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Visual Interactive Linear Programming: The Concept, An Example And An Empirical Assessment Of Its Value In Supporting Managerial Decision-making

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VISUAL INTERACTIVE LINEAR PROGRAMMING: THE CONCEPT, AN EXAMPLE AND AN EMPIRICAL ASSESSMENT OF ITS VALUE IN SUPPORTING MANAGERIAL DECISION MAKING

by

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ABSTRACT

Decision support systems (DSS) and visual interactive (VI) modelling emerged during the 1970s at roughly the same time [Sprague and Watson, 1989], [Belton, 1991]. Both ideas seem to have been driven more by advances in computer technology and increasing management demands than any theory. There are both similarities and differences between them. DSS often use some visual and interactive features [see Turban and Carlson, 1989], but seldom refer to them in terms of a VI model. On the other hand, a VI model is almost always built to support decision-making, and is often referred to as a DSS. Both have developed their own methodology from different perspectives. Their integration should be complementary and should result in models that may answer many questions commonly encountered by both VI and DSS disciplines.

This thesis presents a visual interactive linear programming (LP) model for managerial decision support. The model is unique in its use, information display and user-model interface.

The thesis also empirically investigates the value of the LP-based VI-DSS through comparison with a more traditional LP-based DSS.

The empirical study was conducted at the Western Business School. Data was collected over a period of about seven weeks, during which 80 MBA students voluntarily participated. The analysis of the data provided support that VI-DSS are, on average, more effective DSS for making managerial decisions. The result of the experiment also supported a proposition that VI-DSS aid learning more effectively than non VI-DSS.

This study made research contributions to the area of LP, DSS, and VIM. The study demonstrated that VIM is a better modelling methodology to exploit the existing computer technology and to build improved DSS. The study also demonstrated that visual displays help LP to be used to its full potential and help to make effective managerial decisions.

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During final months of thesis preparation his patience, constructive insights and willingness to edit documents, often at short notice, played a critical role in its progress and completion. He has been such a mentor all along that I have no words to express my gratitude. Back home, people often touch their mentor's feet in a gesture of gratitude and respect. Peter, make it easy for me, let me simply say thanks.

I feel fortunate at Western Business School to have had good research facilities and able teachers. Among them I must mention Dr. Christoph Haehling Von Lanzenauer who was away on sabbatical during my thesis research. He taught me to look at things differently, often challenging personal preconceptions.

Looking back, doctoral program and production of any piece of research would not have been possible without unstinting support of my family members. I would like to express my deepest gratitude to my parents, and most of all, to my wife, Aysha, who often sacrificed her own needs to support me emotionally during whole Ph.D program. I could not have sustained the demand of life without her on my side. With appreciation and affection I dedicate this thesis to her.

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1.0 - INTRODUCTION

Decision support systems (DSS) have been described for about twenty years. An early articulation of DSS by Gerrity (1971) involves "an effective blend of human intelligence, information technology and software which interact closely to solve complex problems." DSS have been built and used from different perspectives, including management science/operations research (MS-OR), and management information systems (MIS), and are now in wide use in business. Yet controversy about DSS definition, lack of classification criteria and inconsistency between the theory and practice of DSS are still causing problems for researchers and practitioners [Mahmood and Sniezek, 1989]. A major problem is in the evaluation of DSS.

DSS classification criteria developed in this thesis show that there are seven types of DSS and that the number of DSS applications are in abundance in some types, while there is a shortage in others. The classification criteria also show that the role of mathematical programming in DSS is limited because DSS provide good, bad or satisfactory solutions but never right or wrong ones. Yet a survey done for this thesis shows mathematical programming (MP) applications with DSS titles providing prescriptive solutions, with little or no attempt to distinguish the DSS from a purely normative technique. The classification criteria further point out that almost all the DSS used in empirical research to study DSS usefulness fall under only one of the seven identified types.

Literature in the applications of mathematical programming indicates that MP modellers increasingly recognise the importance of user-model communication. Many modellers have moved away from using MP because of a lack of tools that help in communicating the mathematical nature of the technique in simple terms [Aggarwal, 1990].

It was noted by Lockett (1985) that with the current MP software it is too easy to lose sight of the real purpose, which is to provide insight and not numbers. Most of the software is traditional and does not allow more than some custom-written, rudimentary interaction. The difficulty for the modeller is to formulate a problem to fit the available software, and to present the solution in whatever form the software allows.

The literature in visual interactive modelling (VIM) provides theoretical, some empirical, and overwhelming experiential support for improved user-model communication. The literature in VIM also suggests that there is a shortage of operational VI-MP models. Therefore, building a visual interactive linear programming (VILP) model as a VI-DSS was taken as the first objective of this thesis. The aim was to build an improved DSS that was free from the modelling difficulties and the user-model communication difficulties commonly encountered in the MP applications.

The second objective of this research was to compare empirically the VI-DSS with another DSS built to address the same problems but having different decision aids. The issues that were compared include DSS effectiveness, support for learning, efficiency, etc. These issues were important for three reasons:

a) Visual interactive linear programming models have not been empirically tested for their effectiveness in a decision support role.

b) Ability to support effective communication with the user or to support learning has not been empirically established for all types of VI models.

c) The difference between graphical and tabular displays for effective decision-making has not been established.

An experiment was conducted at the Western Business School with eighty MBA second year students as voluntary subjects. They were assigned randomly to one of two groups based on the type of DSS assigned to the group. The experiment was conducted one subject at a time during November and December 1992.

The VI-DSS was well received by the subjects, and the results of the experiment confirmed the hypothesis that the VI-DSS was more effective support system. The results also confirmed that subjects learn faster and more systematically with a VI-DSS, but did not confirm a hypothesis that VI-DSS are more efficient. The reason for this was not the inefficiency of the VI-DSS rather the difficulty in controlling the parameters affecting DSS efficiency.

The implications of the experimental results cover LP, DSS and VIM. The potential contribution of this study will apply to both the theory and practice of DSS. Building the DSS, besides broadening the range of DSS models, will help to verify if the VIM approach is more appropriate for building DSS than the one used traditionally in the practice of MIS and MS-OR -- especially when normative modelling techniques are involved. The empirical tests provide practitioners with insights and evidence concerning which DSS are more effective and better suited for a given type of problem. The implication to LP is that existing computer technology can be exploited to develop improved software with which managers and other decision makers can use LP to its full potential, without relying completely on management scientists-operations researchers.

1.1 - OVERVIEW OF CHAPTERS

Chapter 2 provides an overview of DSS. First, conceptual issues are discussed including the development of classification criteria. This chapter also discusses DSS as seen in theory and in practice, followed by empirical research in the field, and concludes with the presentation of the difficulties and opportunities involved in further research.

Chapter 3 seeks some answers to questions raised in chapter 2. The chapter presents a classification of mathematical programming (MP) applications, and a discussion of their use and of the modelling difficulties including user-model interface and implementation. The chapter concludes with a presentation of the opportunities in this field.

Chapter 4 reviews the present state of visual interactive modelling (VIM) and describes the state of VIM practice, model-building methodology, theoretical and empirical support for VIM's usefulness, and the contentious issues that are common to both the DSS and VIM.

Chapter 5 presents the objectives and research methodology adopted for this study. First, the objectives are developed and then the details of the study are presented. Included are a description of the model, experimental framework, hypotheses, and experimental measures.

Chapter 6 describes the procedure adopted for data collection and explains the data analysis performed. The test results are presented in various tables. This chapter also includes a discussion of results.

Chapter 7 concludes the thesis with the implications and limitations of the study.

2.0 - DECISION SUPPORT SYSTEMS

2.1 - INTRODUCTION

The decision support systems (DSS) concept emerged in the early 1970s (Scott Morton, 1971). Today, DSS have become a flourishing major managerial tool used to solve both everyday problems and occasional problems. DSS are in use in manufacturing and service industries, in government and private sectors, in profit and nonprofit organizations, as well as in all functional areas of business [Eom and Lee, 1990b]. Attempts are being made to develop more efficient and effective DSS by taking advantage of ever-advancing computer technology. Studies show that DSS have had, and continue to have, a profound effect on establishments [Alloway, Umbaugh, and Lasden, 1987], [King, Premkumar, and Ramamurthy, 1990]. DSS also continue to offer research opportunities for academics and practitioners in this rapidly developing field.

2.2 - DSS: A CONCEPTUAL FOUNDATION

Although DSS have been recognized for about 15 years, there exists no universal or established definition for them [Keen, 1986], [Turban, 1990]. There are several different definitions in the literature attaching different weights to the three elements of the name itself. The elements in the name "decision support system" have a certain "intuitive validity": any system that supports a decision, in any way, is a "Decision Support System" [Sprague, 1980]. "DSS" has been used so loosely that "virtually every computer hardware and software firm refers to its products as DSS" [Naylor, 1982], including software packages like IFPS which many would call tools to build DSS, or simply "DSS generators" (Sharda, Barr, and McDonnell, 1988].

The definitions that exist are also controversial. One view of a DSS is that it is a major "breakthrough" in aiding decision-makers to solve semi-structured and unstructured problems at the executive level [Keen and Scott Morton, 1978], [Keen and Wagner, 1980]. Other views are that DSS is just a "buzz word", and that DSS contribute to structured-to-unstructured problems at all levels of organizational and managerial decision-making [Sprague and Carlson, 1982].

Keen and Scott Morton (1978) originated the idea of DSS stating that DSS pick up where Management Information Systems (MIS) leave off, while Davis and Olson (1984) contended that DSS are a subset of MIS (Mahmood and Sniezek, 1989). Yet, Naylor (1982) argued that "DSS is a redundant term currently being used to describe a subset of management science that predates the DSS movement."

"DSS are used in areas where the complexity of the process exceeds human abilities to visualize the effects and implications of a decision" [Bozai, 1991], and techniques such as computer simulation, heuristic programming, and artificial intelligence are used to support the analysis and solution of structured parts of the problems. Little (1970) had introduced an idea similar to DSS to enhance MS-OR applicability under the name "Decision Calculus" before Keen and Scott Morton came up with the name DSS. Little defined his "Decision Calculus" as "a model-based set of procedures for processing data and judgements to assist a manager in his decision-making" [McIntyre, 1982, emphasis added]. Today, the term DSS is more popular than the term "Decision Calculus". In retrospect, Bell (1991) writes that "it seems clear that MIS did not invent DSS any more than Columbus invented America." Due to the definitional conflict and debate, some researchers and practitioners continue to follow a particular definition while others have resorted to characterization of their DSS [Alter, 1977, 1980].

Underlying these definitional controversies and inconsistencies there seems to exist among academics and practitioners a perception expressed in a motherhood statement: a DSS is a system designed to assist decision-makers in making better decisions than they could normally make in the absence of the system. Here, "better" implies effectiveness and/or efficiency, and "system" implies both a system of user-computer interactions, and design and implementation of that system [Er, 1988]. The statement incorporates conceptual views given by Gerrity (1971), Keen and Scott Morton (1978), Sprague and Carlson (1982), and Mann and Watson (1984), and "characteristic" views expressed to replace the definition by Alter (1980), Keen (1981), Huff (1985), and Parker and Al-Utaibi (1986), among others.

Sprague (1980) writes that, unfortunately, a restrictive or a broad definition does not help much for it does not provide guidance for understanding the value, the technical requirements, or approaches for developing a DSS. Yet surveys show more than 200 bona fide applications (five years ago) with varying degrees of success [Eom and Lee, 1990a]. DSS continue to flourish despite skepticism, and according to Finlay and Martin (1989), the time has come for it to emerge as a marked force in the business scene.

According to Sol (1987), the focus of DSS has changed over a period of time. In the early 1970s, strong cognitive focus was stressed; in the mid- and late 1970s, interactive computer-based systems were emphasized; and in the 1980s, the emphasis moved to managerial effectiveness by using suitable and available technology [Sol, 1987]. If the history of managerial decision support is traced from before 1971 when Scott Morton phrased his concept "management support systems", then the DSS domain can be pictured as visualized by Simon (1965) and Little (1970), among others.

In describing the taxonomy of decisions, Simon (1965) described programmed decisions as those which are repetitive and routine, and which have a definite <u>procedure</u> to handle them. This description requires that the series of events that constitute a problem have defined and fixed rules to govern their outcome, that every variable of the problem is fully quantifiable, and that the outcome is fully predictable, so that the process can be programmed in a computer to crunch out the solution without human intervention; for example, a game of tic-tac-toe.

On the other hand, Simon (1965) described nonprogrammed decisions as those which are novel and consequential. No single, direct method exists to handle the problems that involves nonprogrammed decisions either because problems of this kind have not arisen before, or their precise nature and structure are too elusive or complex for human comprehension. The problems are so important that they deserve individual treatment. Each event of a problem of this type requires human judgement and subjective analysis to decide its solution; for example, hiring of a chief executive officer.

Keen and Scott Morton (1978) renamed the terms "programmed" and "nonprogrammed" as "structured" and "unstructured", respectively, in developing the DSS concept. Semistructured problems are defined as those problems that lie anywhere on the continuum between structured and unstructured problems.

The reasons for semistructuredness could be many, but uncertainty within the problem seems to be a major one. The process view of a problem can be expressed in three dimensions: <u>input</u>, <u>output</u>, and the <u>process</u> that transforms the input into output. Many authors have indicated that uncertainty can exist in one or more of these dimensions, and have developed models to alleviate or address it [Hartsough and Turner, 1990], [Kuan, Wu, and Huang, 1991].

Addressing input uncertainty was one of the fundamental features of the "Decision Calculus". The philosophy was to use the manager's subjective judgement to estimate the otherwise unavailable data as input to the model. The approach was to say to the manager: "Let's see what your own views logically suggest you ought to do" [McIntyre, 1982].

Later, Sprague and Carlson (1982) added the input dimension to their DSS definition. They said that the DSS are aimed at "less well-structured, under-specified problems that upper management face" [emphasis added] - meaning that there may exist uncertainty about the problem data which requires managerial subjective input to reach a problem solution. In providing the meaning of "support" in a DSS context, Er (1988) stated that the support could range from passive to normative. Passive support allows decision-makers to make their own autonomous decisions, while in normative support the DSS dominate the decision process, leaving managers to input the data.

Finlay and Martin (1989), in considering the developments in decision support software, suggested outcome-uncertainty as a dimension on which DSS lie. They used Thompson and Tuden's (1959) matrix to fit DSS to the other two dimensions: outcome uncertainty, and cause and effect uncertainty. They defined "cause and effect uncertainty" as the "rules governing the way the world operates", or simply the process that transforms inputs into outputs.

Finlay and Martin (1989) used different labels to identify each quadrant of the resulting system (see Table - 2.1).

UNCERTAINTY ABOUT CAUSE AND EFFECT		UNCERTAINTY ABOUT OUTCOME: LOW	UNCERTAINTY ABOUT OUTCOME: HIGH
	LOW	Data Processing System	Decision Insight System
	HIGH	Extrapolatory Systems	Scenario Development System

Table - 2.1: A matrix of decision support systems.
Source: Finlay and Martin (1989)

Given the discussion above, it seems that DSS are developed to overcome human weakness in visualizing uncertain situations. The problems that have been addressed using DSS also attempt to alleviate uncertainty in at least one of the following:

1. Input or data,
2. Output or outcome, and
3. The Process that converts inputs into outputs.

Keen and Scott Morton, among many others, appear to call such uncertain decision situations "judgmental" or simply "semi-structured problems".

A system built to support a situation in which inputs, outputs, and the process are "certain" clearly resembles an Electronic Data Processing (EDP) or Transaction Processing System (TPS) as suggested by Er (1988), and Finlay and Martin (1989). Any other system built to support a situation different from this extreme, under current terminology, is a DSS. These systems are often referred to by other names such as Decision Insight Systems [Golden et al, 1986], Scenario Development System [Finlay, 1986], Extrapolatory Systems [Finlay and Martin (1989)] or simply by the description of the system characteristics.

2.3 - DSS IN THEORY AND IN PRACTICE

A survey of DSS applications in the published literature of the last five years (1988-1992) was conducted. The list of articles was drawn from the ABI/INFORM data base, but because of the lack of a narrow DSS definition, strict criteria could not be used in the selection of articles. However, for the purpose of this research, criteria used in the previous survey of DSS applications conducted by Eom and Lee (1990) covering 1971 to 1988 were used. Their criteria were based on the presence of a description of the DSS, and on the subjective assessment of the DSS authenticity. The survey done for this study also includes applications that are titled DSS and that demonstrate a system for managerial decision-making. Most of the articles for the survey came from *Interfaces, Decision Support Systems, European Journal of Operations Research, MIS Quarterly, Decision Sciences, OMEGA*, the International Journal of Management Science, *Journal of Operations Research Society, IIE Transactions*, and *Computers and Operations Research.*

In order to study the current state of DSS practice, the survey conducted for this study covering 1988 to 1992 and the survey conducted by Eom and Lee (1990) covering 1971 to 1988 were both analyzed. The surveys show that in addition to the absence of an established DSS definition, lack of DSS classification criteria and lack of suitable tools to build DSS hinder the research and practice of DSS. The conclusion drawn was that a discrepancy between theory and practice exists, and reconciliation attempts are limited.

Gray and Lenstra's (1988) basic paradigm for DSS architecture has three major components: Data-base, Model-base, and Human interface. The user interacts with the components (and each component interacts with the others) to make a decision. The Operations Research (OR) field has been concerned with three components, data, model, and man-machine interaction and its integration, since long before DSS came on the scene. A difference is that the DSS cannot provide optimal solutions due to the semistructuredness of the problem [Ackoff, 1977]. The solution may lead to a decision that can be good, bad, or satisfactory, but not right or wrong. Yet, some applications surveyed seemed to take the prescriptive output from the DSS as the answer to the problem (See [Hill, 1989], [Siskos et al., 1989], [Le Blanc, et al., 1990]).

Most applications in the survey show a lack of connection to the database-modelbase-and-interface paradigm. The impression created by Sprague's (1980) view of DSS is that the user draws selective data from a large database managed by DBMS, and a model from a large modelbase managed by MBMS, to conduct "what if" analyses. Applications surveyed did not show the presence or need for either DBMS or MBMS, since there were no large or dynamic lists of data that required frequent processing before using the DSS. A majority of applications surveyed used static data as organizational or system parameters combined with managerial subjective data as input to run their DSS. Similarly, many applications did not have, nor had the need for, a model base. Most of the DSS surveyed were designed for one situation and involved one symbolic or MS-OR technique. In a few cases where more than one technique was used, they were all integrated into one, since the output of one technique was used as input to the other. The techniques could not be isolated from each other, nor did they address any situation other than what was originally intended (See [Kwak, et al., 1989], [Tufekci, et al., 1991]).

Some applications in the survey seemed to address conceptual generic problem-situations. These applications presented the aggregated and arithmetically processed data in tabular and/or graphical form in an effort to be useful in solving some organizational problems (See [Carpenter, 1991-92], [Forgionne, 1991a]). Other applications addressed specific problem-situations with a specific mathematical technique [Dyer, et al., 1990], [Bell, et al., 1990], [Forgionne, 1991].

The surveyed literature indicates a lack of DSS-software capability in providing features suggested by the DSS design and development proponents. Gray and Lenstra (1988) indicate that the major software packages for DSS are modelling languages (IFPS) or spreadsheet packages oriented to solving accounting relations. As a result, the principal DSS applications have centered around problems that can be solved using these packages. A survey of DSS applications shows many other stand-alone specific packages under their own names such as: CONCORD, SICIS, ADBUDG, CALLPLAN, TRADES, DECAID, GODESS, MAUD, etc., but the decision task involved in them did not seem to have gone beyond the scope of the popular software packages [Sharda, et al., 1988]. Except for simulation software and in-house developed software, a general purpose software package conducive to building a DSS with symbolic and MS-OR techniques and user-defined iconic and representational displays was not found.

The literature provides description after description of various systems which their authors choose to call "DSS" but there is no attempt to distinguish one type of DSS from another. The absence of a framework not only makes it difficult to identify a DSS, but makes it impossible to say anything meaningful when attempting to compare two or more DSS [Naylor, 1982], [Mahmood, and Sniezek, 1989]. Silver (1988) writes on the lack of criteria by which to differentiate DSS suggesting that "immediate focus of research attention should, therefore, be (placed) on developing appropriate means for describing and differentiating environments and especially systems."

In the absence of an established criterion, if we select the input-output framework given in Figure - 2.1, several environments (problem-situations) can be seen. To build a DSS, common situations can be distinguished from the uncommon ones. The surveyed applications can also be mapped in the framework to show the lack of applications in certain environments and the concentration in others.

For establishing a classification criteria it is important to differentiate the process view from the problem view of a given situation - since they are often confused. The inputs and outputs in the process view are not necessarily the inputs and outputs in the problem view, they could be reversed. For example, consider the following:

refinery ABC receives several kinds of crude to be processed into many grades of gasoline.

Under the process view, types (and/or quantities) of crude are inputs and different grades (and/or quantities) of gasoline are outputs. If the decision maker wishes to determine the types of crude required to process for the given grades of gasoline, then under the problem view, the types of crude are outputs and grades of gasoline are inputs. On the other hand, if the decision maker wishes to determine the grades of gasoline that can be obtained by processing given types of crude then types of crude are inputs and grades of gasoline are outputs as in the process view.

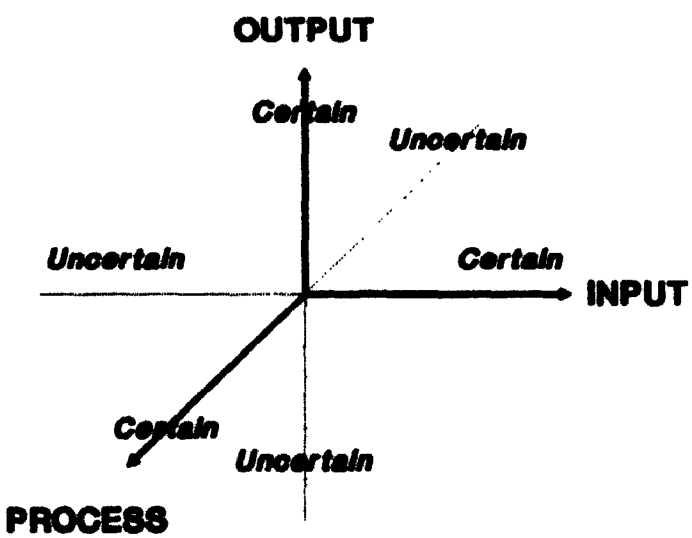

Figure - 2.1: Three dimensions of a DSS

In the DSS framework (Figure - 2.1) uncertainty is expressed as a state in which information is lacking. For example, information concerning a parameter may be known completely and accurately on one extreme, and on the other extreme, information may not be known at all -- even the existence of that particular parameter. A parameter with information in between the two extremes is viewed as an uncertain parameter.

The framework yields seven problem situations that are listed in Table - 2.2 below (an eighth was added for clarity). As the parameters of the framework - input, process, and output - are altered, a different situation results calling for a DSS with specific characteristics to resolve the situation. For the DSS to be useful and effective, an appropriate technique must be built into its model base. Assuming a DSS for each extreme situation the resulting seven DSS would appear as shown in Table - 2.2.

<table>
<tr><th rowspan="2">DSS TYPES</th><th colspan="3">UNCERTAINTY IN</th><th rowspan="2">A TYPICAL MODELLING TECHNIQUE USED</th></tr>
<tr><th>INPUT</th><th>OUTPUT</th><th>PROCESS</th></tr>
<tr><td>1</td><td>High</td><td>High</td><td>High</td><td>Heuristic</td></tr>
<tr><td>2</td><td>Low</td><td>High</td><td>High</td><td rowspan="2">Descriptive Techniques
Ex. Regression</td></tr>
<tr><td>3</td><td>High</td><td>Low</td><td>High</td></tr>
<tr><td>4</td><td>Low</td><td>Low</td><td>High</td><td>Arithmetic
Calculus
Statistical</td></tr>
<tr><td>5</td><td>High</td><td>High</td><td>Low</td><td>Simulation</td></tr>
<tr><td>6</td><td>Low</td><td>High</td><td>Low</td><td rowspan="2">Normative Techniques
Ex. LP</td></tr>
<tr><td>7</td><td>High</td><td>Low</td><td>Low</td></tr>
<tr><td>8</td><td>Low</td><td>Low</td><td>Low</td><td>Not a DSS</td></tr>
</table>

Table - 2.2: DSS with different model bases

The first type of situation where all three parameters have high uncertainty seems most difficult to support, but unfortunately it is a common environment in which difficult decisions are made. In this type of situation, nothing is known with precision and a single analytical technique cannot capture the essence of the whole situation. The decision-makers rely on rules of thumb or heuristics [Thorsen, Vidal, 1991], or they break the problem situation into sub-problems and apply MS-OR techniques to the structured parts to alleviate the uncertainty (See examples in [Moribayashi, M., Wu, C., 1990], [Aggarwal, 1990]). The best one can do in such situations is to use these techniques with a "friendly" user interface and hope that a few interactions would lead to some insight and, consequently, to a satisfactory decision. The empirical study by Cats-Baril and Huber (1987) suggests the usefulness of heuristics but also shows low user confidence in these methods. The need for more research on the design of heuristics used in addressing ill-structured problems has been suggested by them. Unfortunately, no empirical studies have been published that involve combinations of MS-OR techniques on a DSS.

The second and third types of situations are formed when either input or output has low uncertainty, and the process that transforms input into output has high uncertainty. Due to high process uncertainty and knowledge of only one parameter out of the three, modellers frequently take a historical perspective and try to map the known inputs with the known outputs (historical data) in the hope of learning about their relationship. Since the technique is descriptive in nature, it helps only in predicting the future behavior of the system, but cannot identify the "best" course of action [Davis and McKeown, 1984]. Managerial judgement is, therefore, needed for decision-making.

Several DSS are available that have used such techniques. Dyer et al., (1990) described a DSS that uses regression analysis to aid oil and gas exploration. This DSS was developed because the managers had the data concerning the attributes of plays (a play is a geographical location or other characteristic that may be widespread over a large area), but did not have a method to choose "good" plays realistically, nor could the managers decide how many geologists or geophysicists to assign. Play proponents would influence managerial decisions by emphasizing the geological nature of the play, favorably adjusting the volume of the expected reserves, and using skilled presenters to stress strong points and to pass over the weaknesses in a play. Managers had difficulty making a realistic selection in the absence of non-geological factors and a systematic means of comparison. The DSS was considered successfully implemented for effective and routine use in this application.

Similarly, Hadzinakos, et al., (1991) developed a DSS to estimate landslide favorability by assessing the utility function. Elimam (1991) used mathematical models with regression analysis in their DSS to estimate university enrolment based on admission policies. In all of these cases, the technique provided an understanding and a possible scenario of the case on which to base the managerial decision.

The fourth type of situation in the framework has low uncertainty in both the data input and output, but not in the process. Since input and output have low uncertainty, a symbolic model can be developed using functional relationships [Davis and McKeown, 1984]. Often the relationships can be expressed with statistical and arithmetical functions, for example, the relationship between sales and commission income.

This kind of situation is common in problems dealing with finance. Arend (1988) describes a risk management DSS (STORM) which supports loan dealings with foreign exchange, financial futures and options. The application conforms to this kind of DSS. The literature presents many other applications in the area of finance based on spreadsheet and finance-language modelling (e.g IFPS) [Forgionne, 1991], [Carpenter, 1991-1992]. The applications of this type of DSS include forecasting [Mahmoud, 1988], inventory management [Hill et al., 1989], production management [Kwak et al., 1989], etc. There are very few applications in this area that have high process uncertainty. The majority of published applications seem to have low to medium uncertainty. According to Saaty (1989), such applications involve number crunching based on scale manipulation - "the process of taking a variety of numbers and running them through arithmetic procedures that produce new sets of numbers thought to have more meaning than the original collection."

The fifth type of situation relates perfectly to simulation. In this type of situation, the process that transforms inputs into outputs has low uncertainty, while input and output both have high uncertainty. In simulation models, the real system is imitated by using probability distributions as input to randomly generate the various events that occur in the system. The output is a series of statistical observations (see Hillier and Lieberman, 1990, P-857) which are then subjected to managerial decision-making. The literature presents a significant number of simulation-based DSS. In fact, the survey done by Eom and Lee (1990) shows simulation to be the most widely used technique in DSS. It should come as no surprise, because simulation is a well-established MS-OR technique and the current visual interactive methodology has narrowed the gap so much that one could conclude that many simulation models, on their own, may be DSS.

The sixth and seventh types of DSS have certain processes and uncertain inputs or uncertain outputs. From a technical point of view, if two of the three parameters are known (i.e. certain), then the third can be determined. If one of the certain parameters is the process, then we can trace the procedure from known inputs to find the outputs, or working backward we can estimate the set of possible inputs by tracing the path from the known outputs. The situation calls for optimization of the third (only unknown) parameter where the objective is clearly defined and the constraints and the procedure to achieve the objective are clearly known. In MS-OR, terminology the technique is obviously a normative technique.

Real world situations calling for this kind of DSS are very common. Eom and Lee (1990a) in the classification of DSS applications say that "twenty-eight percent of all applications are . . . optimization models which generate the optimal solution consistent with a series of constraints." Other studies also suggest that normative tech iques are the most commonly embedded technique in the DSS [Aggarwal, 1990]. The use of the technique in this kind of situation, however, raises a conceptual difficulty: in practice, the input (or the output) (supposedly the known parameter) is usually never known with certainty. If the input (or the output) were really known, then a DSS would not be required - the technique could alone yield the decision as a prescriptive solution. If the input is a little uncertain as it may be in the real world, and assumed as such in the DSS, then the situation leads to other types of DSS, where two or three parameters are uncertain. The role of a normative technique in the DSS is then limited, or even questionable.

A situation with fairly certain process and moderately uncertain input or output seems conducive to a DSS with a normative technique. However, a proper methodology must be employed to distinguish the DSS from a purely normative technique. Unfortunately, it is not easy and the literature has very little to offer as help. Aggarwal (1990), in developing such a DSS, states that the business situations are "either too complex or do not conform to the restrictions imposed when using linear programming; it is necessary to resort to simulation." To develop such a DSS, modellers have either broken the problem-situation into sub-problems and used a combination of techniques to support decision-making, (eg., [Hugo, Scholtz, Sinclair, and Curtayne, 1989], [Moribayashi and Wu, 1990]), or the modellers have steered clear of normative techniques and have instead used simulation, heuristics or both, [Thorsen et al., 1991], [Aggarwal, 1990]. The survey shows that most applications which include a normative technique made no attempt to justify their title as a DSS.

An examination of DSS applications over the last 20 years under the input-process-output framework suggests that there is a large number of applications for some situations and a lack of applications for others -- especially when uncertainty in any dimension is moderate to high.

Cats-Baril and Huber (1987) write that "unfortunately, DSS in practice almost invariably support decision-makers dealing with moderate to well-structured problems." Finlay and Martin (1989) write that "until very recently, DSS have been concerned solely with processing quantitative material and with helping individual decisions." This DSS survey does not show that applications have made much improvement since that time. Clearly, there is a need to extend the DSS to solve other kinds of problems commonly faced by managers.

2.4 - DSS: EMPIRICAL STUDIES

The number of DSS applications published has steadily increased since 1971. The survey done by Eom and Lee (1990b) covering 1971 to 1988 found only one application in 1971 and 29 in 1987. The survey done for this study (covering 1988 to 1992) found more than 37 DSS applications in 1990: an indicator of the wide acceptance of these systems in day-to-day organizational applications. At the same time, the number of theoretical research papers has also increased, especially in areas such as decision theory, DSS design and development process, and the establishment of optimal design parameters (eg., [Saaty, 1989], [Bozai, 1991], [Mahler, 1991]). Yet, the gap between theoretical and practical usefulness (or effectiveness) of a DSS has not been narrowed. At least fourteen empirical studies and an equal number of field and case studies have been conducted since 1971 to find the usefulness of a DSS, but the final verdict is still inconclusive.

Most field studies and case studies claim that DSS are useful tools in managerial hands. This claim, however, is based on the frequency of DSS usage and user satisfaction (eg., Michelman and Kim, 1990) and [Watson et al., 1989]. A few authors have argued that "DSS usage" and "user satisfaction" as performance measures are used because of the lack of other performance measures under field conditions, and under the assumption that the more a system is used the greater the benefits are. Udo (1992) empirically tested this assumption and found no significant relationship.

The laboratory tests conducted to test the usefulness of DSS have shown mixed results. The salient features of these tests conducted between 1978 and 1992 are summarized in Table - 2.3 below. The features help partially to explain the inconsistency in the test results. It should be noted here that the table presents the summaries only from the viewpoint of the effect of DSS availability on the decision outcome, although the studies listed have invariably investigated many other issues.

AUTHORS	DSS FEATURES	RESULT
Benbasat and Schroeder 1977	Single product inventory model	Model users had lower cost, but took longer to decide
King and Rodriguez 1978	Corporate strategic planning	No significant increase in decision quality
Chakravarti et al.1979	Advertising budgeting model	Model users had lower profits
Benbasat and Dexter 1982	Single product ordering and scheduling simulation model.	Model users had higher profits.
McIntyre 1982	Promotion allocation model	Model users had increased profits, and a faster rate of improvement.
Eckel 1983	Fortran-based, batch processed, probabilistic, profit-maximizing, Production, advertisement experimental game model	Model users had higher profits but an insignificant difference in alternatives considered.
Dickmeyer 1983	Interactive financial planning model; Computer, paper experiment.	Model users had higher changes in policy preferences
Fripp 1985	Regression and arithmetic- based forecasting and financial game model.	Inconclusive result. Non- model users achieved asset position in between two model user groups.
Aldag and power 1986	Strategic management Model written in BASIC	No significant difference in decision quality
Goslar et. al 1986	IFPS-based marketing strategy model	DSS users had no significant difference in performance
Cats-Baril and Huber 1987	Career planning heuristics on computer or paper	DSS users (computer) did not have higher performance
Kottemann and Remus 1987	Production scheduling model with a spreadsheet type interface.	Non-DSS users outperformed DSS users

Sharda et al 1988	IFPS-based production and plant expansion model	DSS users had higher profits
King, Premkumar, Ramamurthy 1990	Arithmetic-based financial model with access to CRSP, and COMPUSTAT data bases[1]	DSS users outperformed non-users, but the sample size was too small

Table - 2.3: Empirical tests conducted, between 1978 and 1992, to evaluate DSS usefulness

The studies published prior to 1984 generally show a positive effect of DSS on decision-making. The DSS in these studies were usually batch processed computer programs and the experiment in the study emphasized the use and non-use of a computer, rather than dynamic decision aids produced by the system. The subjects could use a "black-box" instead of a computer to help them in decision-making: the subjects could not see the model or its underlying assumptions. Therefore, the DSS seemed to have little relevance to DSS widely used in the present time.

The studies published after 1984 are inconclusive: three studies show a negative effect while two of them show a positive effect, and the remaining two are inconclusive. There could be a myriad of reasons for the mixed results, but some likely ones as noted in the previous studies are:

1. METHODOLOGICAL DIFFERENCES: All the studies that used a subjective rating have shown an insignificant difference in DSS effect, while studies using "hard"

[1]: COMPUSTAT and CRSP (Center for Research on Security Prices) are commercial data bases.

measures have shown either positive or negative effect. Hard measures have intuitive validity and consistency. They are, as noted by Keen and Scott Morton (1978), more accurate measures of decision performance. (See also [Sharda et al., 1988]).

2. DIFFERENCES IN THE MODEL CONTENT: Studies that required the subjects to use the model over a period of time, and which showed the model to have some "learning" effect, resulted in positive DSS effects, whereas others resulted in a negative effect.

3. COMPLEXITY OF TASK: If the subjects in a study could perform the task without needing the aggregation or manipulation of the raw data by the system, then such studies have indicated either a negative or insignificant effect, while other studies have shown a positive effect. It is human nature to carry out a task intuitively unless there is more than a "thank-you" at stake for performing the task. This seems to be the case in many studies cited.

4. ABSENCE OF DSS RANGE: Most of the models used in these studies are arithmetic-based models. These models all belong to a single type of DSS (type 4) in the input-process-output framework. Obviously, empirical tests of other kinds of DSS are required if meaningful conclusions as to generalizability are to be drawn.

5. LACK OF SUITABLE SOFTWARE TO BUILD DSS: All the models used in these studies are developed by the researchers using a fourth generation language or a software package such as IFPS. These packages have been referred to as DSS generators (Sharda et al., 1988) when all they do is perform number crunching for a predefined arithmetic formula, statistical function, or an MS-OR technique, and present the output numbers in a tabular and/or graphical form. All the output data are not necessarily required for quality decision-making. Nor does the presentation of data in a histogram, line graph, or a pie chart guarantee a quality decision. Software conducive to building innovative decision aids is required: i.e., aids that are conceptualized by the users/modellers to be useful in decision-making. Then, the software could help in whatever is required to operationalize the aids.

6. RESEARCHER'S BIAS: Since most models in the empirical studies are developed by the researchers themselves, their bias might have inadvertently effected the results. Kottemann and Remus (1986) state that:

> "When a researcher hypothesizes that a DSS treatment will be beneficial, it is analogous to a well-intentioned DSS designer developing a system which he/she believes will improve decision making. When a researcher, in fact, finds the opposite true, it is analogous to the development of a DSS that may hinder rather than help decision-making."

7. IRRELEVANT QUESTION TESTED: The published studies have tested and compared effectiveness according to the availability of a computer system - supposedly a DSS.

However, by the "agreed definition" of a DSS, a system is not a DSS if it does not help in decision-making. Therefore, a relevant question to test is not whether a DSS is useful in decision-making, but how useful it is. One way of measuring this would be to use two DSS addressing the same issue but with different decision aids.

2.5 - DSS: NEED FOR FURTHER RESEARCH

The foregoing discussion provides an account of the discrepancy between the theory and practice of DSS. It underlines five major difficulties encountered by DSS modellers and researchers:

1. The literature has very little information about the use of mathematical techniques in a decision support role. With the exception of simulation, this holds true for MS-OR techniques in general, and normative techniques in particular. "Much of the research literature concentrates on the procedural aspects of building support systems rather than on the substantive issues of their content" [Silver, 1988]. As a result, there is a clear need for a focus on the content of DSS.

2. Due to the fact that there is so little information about attempts to build such DSS, a methodology for building the DSS itself is lacking and, therefore, needs to be established.

3. Except for simulation software, there is hardly any other software that is conducive to building a DSS with innovative decision aids and normative MS-OR techniques. Most of the applications are centered around modelling languages (IFPS) or a spreadsheet type of package.

4. DSS being content free, i.e., meaning different things to different people [Turban, 1990], has led to controversy and inconsistency in the DSS definition. It poses many difficulties for academics and practitioners. The DSS concept is in itself a problem, much less its empirical evaluation. So far, a limited number of empirical studies have been conducted to determine the DSS' usefulness. These studies have confined their scope to include only structured to moderately structured problems, and only one of the seven identified problem-situations -- yet they found conflicting results. Authors of the studies suggest more research is needed [Aldag and Power, 1986], [Cats-Baril and Huber, 1987], [Sharda, et al., 1988].

5. Eom and Lee (1990 a) write that in spite of 20 years of cooperative efforts by theoreticians and practitioners to develop specific DSS, many of the goals in the DSS field remain unfulfilled.

3.0 - APPLICATIONS IN MATHEMATICAL PROGRAMMING

3.1 - INTRODUCTION

In the preceding sections it was argued that mathematical programming in a DSS poses conceptual difficulties and its use in a decision support role is limited. Many DSS modellers have moved away from using MP in favour of simulation because business situations are "either too complex or do not conform to the restrictions imposed when using linear programming" [Aggarwal, 1990], or because the use of the technique requires LP knowledge which an average manager lacks [Locket, 1985]. The following section presents a literature review on MP. It attempts to seek answers to questions such as: Where, How, and Who uses MP? What is the magnitude of the benefit received, if any? What are the problems and opportunites for further research?.

3.2 - MP-BACKGROUND

Mathematical programming (MP) has existed for over forty years as an established technique to solve normative problems. The literature suggests that much effort has gone into developing several MP techniques including Linear programming (LP), Integer programming (IP), Mixed-integer programming (MIP), Goal programming (GP), and

Nonlinear programming (NLP). Textbooks are available that deal entirely with a single technique and provide many application examples. The examples cover a wide range in almost all walks of business. There is more to be learnt yet about the nature of real-world problems to which MP can be applied, the difficulties faced in solving these problems, the opportunity that exists for further improvement, and the benefit received from such applications.

In the early and mid-seventies, publications of bona fide applications of mathematical programming were almost non-existent compared to theoretical papers published during that period. Most of the theoretical papers were based on technical developments of MP algorithms, and the reported numerical examples were "confused" as real applications (none of the examples proved that any real savings were made) [see Lockett, 1985]. Nevertheless, the number of bona fide applications published increased significantly with time. In 1973, out of 21 papers published related to the MP, there was not a single bona fide MP application paper. In 1979, out of 19 papers there were four papers with MP success stories, and in 1988, out of 18 papers nine were MP application papers. In 1991, out of 31 papers, 12 seemed to be true MP applications. Professional journals like *Management Science, European Journal of Operations Research, Journal of Operational Research Society,* and *Decision Sciences* have increased the proportion of the application-oriented papers published over time, even though they are traditionally theoretical journals. *Interfaces*, on the other hand, has made the highest single contribution in reporting bona fide applications with verifiable benefits. Almost 80% of the application papers surveyed for this study come from this single journal.

Published applications of MP techniques have not only grown in number, but also have been applied to many areas for the first time. Initially, the MP techniques were applied successfully to areas such as oil blending where minuscule changes in the parameters could result in significant changes in dollar amounts. MP techniques now have been applied to many kinds of problems with varying degrees of success and benefits.

3.3 - MP-CLASSIFICATION

Before classifying the published papers according to the field of application, the intention was to separate them into pure MP applications and applications derived from certain novel theories or ideas. However, this was difficult to do. Except for two papers, Chandy and Kharabe (1986), Kananen, Korhonen, Wallenius, and Wallenius (1990), all were direct MP applications but had used novel ideas to formulate or mould the problem into an MP framework. Chandy and Kharabe (1986) used the work of Yawitz, Hempel, and Marshall (1976) to develop an MP model to help treasury bill dealers make better investment decisions. In their paper, they developed certain constraints with a few probabilistic variables estimated and conformed to the Yawitz et al., (1976) paper. Similarly, Kananen et al., (1990) converted Noble Laureate Wassily Leontief's input-output economic models, which were traditionally solved using matrix algebra, into goal programming models. In most of the surveyed papers, explicit conversion of theoretical models from other disciplines, like this one, was not found, but novel problem situations have been found quantified in the MP framework.

In classifying the surveyed papers, the intention was also to separate the papers into one-time applications versus operational application-models, but only one application paper [Jennergren and Obel, 1980] described a one-time application. This one-time application model was used for the strategic planning of school systems in Denmark for the year 1992 based on existing demographics and physical facilities. This model has the potential to be an operational model for subsequent years with little change in the MP formulation, but it has not yet been used in this manner. It seems that one-time applications are not attractive to practitioners or researchers. One explanation could be that the tangible benefits received from such applications do not justify the time and effort needed to address such problems using existing OR tools and methodology. It is also possible that such applications are generated, but the results are not published.

INDUSTRY		NUMBER OF APPLICATIONS
1	Real-Estate	2
2	Manufacturing	7
3	Chemical/Processing	3
4	Transportation	4
5	Finance and Banking	5
6	Educational Institutions	3
7	Agriculture and Forestry	3
8	Recreation	1
9	Defense	3

Table - 3.1: Distribution of MP applications in industry.

The first type of classification of the application papers is based on the industry to which the technique was applied. As shown in Table - 3.1, the papers fall into eight different categories. The listed categories seem well-balanced in the number of applications. The numbers shown d› not necessarily mean that the application involves the main stream function of the category. For example, the application in the recreational category does not involve the selection of the best among many recreational activities. Instead it is a straightforward man-power planning application in a recreational facility.

Applications in the hospital/medical field were expected to be among the published papers surveyed, but contrary to expectation none was found. Textbooks provide several examples in this area, including the popular diet problem, but it seems that the technique was either not applied to real problems, or the research was not published in the leading MS-OR journals during the last 10 years.

	BUSINESS FUNCTION	NUMBER OF APPLICATIONS
1	Man-Power/Labour Planning	5
2	Strategic Planning	6
3	Production Planning	7
4	Resource Planning	8
5	Transportation	2
6	Purchasing	4
7	Market planning	1
8	Investment planning	1

Table - 3.2: Distribution of MP applications according to Business function

Table 3.2 shows the number of MP applications and the functional area in which they were applied. As the table shows, MP techniques applied to resource, production, strategic, and man-power planning are the most popular functional areas, while market and investment planning are the least preferred areas -- or the most difficult to model in an MP framework. Since functional areas are inter-related and MP applications are meant to allocate resources in one form or another, a few applications listed in Table 3.6 fall into more than one functional area, for example, resource and production planning, resource and man-power planning, strategic and man-power planning. Similarly, application papers falling under the same functional area have many similarities, but the situational problem in each application paper is unique, and as such possesses a unique MP formulation.

3.4 - MP-MODELS

The problems in the application papers surveyed are formulated using three to ten types of constraints, although the individual number of constraints per model ranged from 156 to 2000. Similarly, fewer than 10 types of decision variables were used, although the total number of variables per model surpassed 160 and in some cases was up to 3000.

To solve the MP problem, the researchers used whatever computer package was available. In a few cases custom-coded programs were also used (eg. [Bhatnagar, 1981], [Marsten, Muller, and Killion], [Glassey and Mizrach, 1986]) and in some other cases, new packages that suited the problem better were acquired [Benseman, 1986]. In most cases, however, the computation was carried out using mainframe computers that utilized software packages such as SAS/OR, LINDO, KETRON's MPS3, and IBM's MPSX with OMNI or another matrix generator. Some applications used spreadsheets [Evans, 1986] and also micro-versions of the mainframe software packages (traditional software).

The surveyed applications show that IP and MIP are more realistic for real world problems than LP. In several applications, however, LP was used even though IP or MIP were said to be more appropriate. Often LP was employed in place of IP or MIP purely for convenience, but in such cases, the effect on results was argued to be insignificant.

3.5 - MP-INTERFACE

The applications surveyed exhibited little algorithmic difficulty, but were found to indicate difficulties in communication with the users. Many authors called their applications "decision support systems". In such applications, it was not clear whether the users needed MP background or not, nor was it clear if the user could interact directly with the system or only through a specialist. In many applications, it was unclear what kind of support the system gave beyond the prescriptive solution of the problem.

A few modellers have used spreadsheets to solve LP problems and then recast the solution into a more managerially meaningful format (eg., [Evans, 1986]). The use of spreadsheet seemed effective for small to medium-sized problems. The relative advantage was the general familiarity with the software and the ease with which a decision-maker could examine the solution and alter the parameter values. The drawback, however, was that it was static and rigid in its display format. It was static in the sense that it could provide only one state of the problem situation at a time - like any other batch processing software. If a value was changed in any "cell", the whole spreadsheet was adjusted to reflect the change - as though presenting another state of the problem situation. An appreciation for relative differences was hard to grasp under this output format.

For large problems spreadsheets were being used in combination with traditional mainframe LP software like IBM's MPSX or KETRON's MPS3. When spreadsheet and other LP software were jointly used then spreadsheets were typically used for data input while the other software for matrix generation and solution. Use of such spreadsheets for model formulation, data input, model algorithm and solution output in small problems might have been effective, but for large problems there was a fear of 'information overload'. The size of a spreadsheet with data, solution, and related analysis could be so huge in larger problems that it would be very difficult to browse or select the relevant information. Often, it is only a small fraction of the decision variables of LP that are of managerial interest [Churchman and Schainblatt, 1965]. There may not be a need to present everything that an LP generates; instead the display could be limited to input and output variables that a decision-maker specifies that are of interest to him/her. Further analysis, if required, could be carried out selectively at the discretion of the decision-maker.

Spreadsheet software are being continuously improved over their previous versions and are also being upgraded to exploit the emerging micro-computer capabilities. Recent spreadsheets are more flexible and are coming with MP solvers, but they are yet to prove managerial suitability for large LP problems.

Many authors recognize the importance of the user-model interface. Wheeler (1985) states that "whatever level of sophistication of the numerical algorithm used in the LP system, there must be effective communication with the user." With the current software it is too easy for the modeller to lose sight of the real purpose, which is, in the words of Geoffrion (1976), to provide insight and not numbers. Most of the software available has been traditional and does not allow more than some custom written rudimentary interaction. If all the modeller has is a hammer, every problem looks like a nail. The difficulty for the modeller is to formulate a problem to fit the available software, and to present the solution in whatever form the software provides.

Increasingly, artificial intelligence and graphic technology are being employed to enhance communication by developing interactive front-ends (user-input communication) and visual back-ends (output-user communication) of LP models. Ma, Murphy and Stohr (1989) present a design of an interface that uses artificial intelligence techniques to help operations researchers and managers formulate large linear programs. Binbasioglu and Jarke (1986) discuss the possibility of using artificial intelligence to allow LP-naive users to present domain specific formulations. Krishnan (1990) presents PM* (PM-star), a knowledge based language designed to help nonexpert users construct LP models in production, distribution, and inventory planning. Similarly Choobineh (1991) presented SQLMP, a data sublanguage for representation and formulation of LP models.

Greenberg (1987) presents a natural language (i.e., English) discourse model to explain a linear programming model, and possibly its computed solution. Kimbrough, Pritchett, Bieber and Bhargava (1990), and Bieber and Kimbrough (1992) discuss the usefulness of hypertext and hypermedia based DSS in communicating with the users. Similarly there are graphical interfaces for LP [Cleaves and Baker , 1990], [Kendrick, 1991]. These new interfaces have yet to be commercialised and to prove their usefulness. Many authors have also tried combining two or more pieces of commercial software through an interface, and have added some managerial value to their application. Some have developed their own to meet their specific needs [Buchanan and McKinnon, 1991].

Buchanan and McKinnon (1991) developed an interactive financial model with LP/GP applications. The model retrieved data from various sources and performed financial analysis in an input-output format, while, if desired by the decision-maker, it optimized an input variable. The displayed data were limited to those variables that were specified by the manager. The useful quality of the financial model was its ability to present the sensitivity of the output variables graphically. If the value of an input variable was increased or decreased, an immediate response could be noticed in the output. This sensitivity, however, seemed limited to the input/output variables corresponding to the financial model, since variables in LP do not always have the same kind of one-to-one direct relationship as do variables in the financial model. It requires a lot more manipulation of variables in LP just to include them in the model. Nevertheless, a selective analysis, as in Buchanan and McKinnon's model, can be performed if it is useful to decision-making.

3.6 - IMPLEMENTATION

The majority of the models surveyed presented the evidence of implementation and disclosed the magnitude of benefit to the firm. The firms were said to have reaped financial benefits that ranged from $100,000 to $2,000,000 per year. In two exceptional cases, firms gleaned between 40 to 68 million dollars [Bean, Noon, and Salton, 1987], [Eiger, Jacobs, Chung, Selsor, 1988]. These benefits are purely monetary, separate from any intangible advantages the users/firms might have received. A few application papers surveyed did not disclose the magnitude of benefits received, but the benefits were felt to be significant.

On the other hand, in spite of the many success stories, the lasting impact of OR on management decisions is still in doubt [Huysmans (1978) cited in Hilderbrandt, 1980]. The fact remains that only a small fraction of OR results are being used. The benefits should not mask the complications encountered during implementation. Typical difficulties are expressed by Lawrence (1973) who was among the early authors of LP applications:

> "The difficulties of accepting a linear programming model are its failure to cope with certainty adequately and the problem of estimating all the costs. Perhaps its most serious drawback is its mathematical complexity since if it is to be used effectively and generate confidence its structure must be understood by the client.

....., personnel function has least experience of mathematical models and a quantitative approach." ([Lawrence, 1973] quoted in [Lockett, 1985])

The difficulty expressed in 1973 is still being expressed in 1992. Over this period of time, authors have outlined their experiences in the implementation of the models. Their experiences contradict some common beliefs and strengthen some others.

Implementation is the key factor to the success of any O.R. tool, and its acceptance by the intended users determines the degree of success. Since user acceptance depends on the user's understanding of the technique, many authors ([Hilal and Erikson, 1981], [Boykin, 1985], [Avramovich, Cook, Langston, and Southerland, 1982]) argue that it is absolutely critical to involve management and users in the building process of the model. Yet Ball Jr. (1985) uses his long consulting experience to observe that getting management more involved and more knowledgeable in the work, and therefore more supportive of it, is nice, but "it just does not work - executives like to decide, not analyze." The papers surveyed here seem to provide the evidence that implementation is successful if managers gain something obvious or concrete that will alleviate their immediate problem. The benefits, however, need not be monetary - MP could be a means to the solution of a different problem leading to monetary gain.

Brosch, Buck, and Sparrow (1980) wrote that one reason for the successful implementation of their model was that the problem they sought to solve was of immediate concern to the top management, and the model output indicated reduced spending levels and increased revenues. In many other cases development and implementation of O.R models has occurred because of mounting pressure from top management to solve a certain problem, but at operational levels, efforts to solve the problem with traditional procedures have reached either an impasse or experienced failure (eg., [Von Lanzenauer, Johnston, and Shuttleworth, 1987]). The IP application in real estate [Bean et al., 1987] for example is the result of the failure of the older system to meet management expectations and goals. In some other cases, implementation has been achieved as a result of new orders or directives from top management [Avramovich et al., 1982]. One example is the FORPLAN in the national forest planning [Field, 1984], which was triggered by the National Forest Management Act of 1979 and directed by the U.S. Congress. The details of the regulation led managers to develop a "constrained optimal solution to a multi-product problem." Implementation of a model has also sometimes occurred simply because decision-makers either were no strangers to O.R, or they had nothing to gain by resisting it - examples include [Glassey et al., 1986], [Jennergren, and Obel, 1980], [Gosselin and Truchon, 1986]. These examples show that involving management in the process of model development is impractical and, therefore, should not be a priority. Management is not enthusiastic about every model the OR department develops. On the contrary, managers would prefer not to change something that is not problematic for them. As the saying goes -- "if it ain't broken don't fix it." Management seems to agree with that.

In this survey no evidence was found of the truth of the notion that "the models with simplified or unrealistic assumptions tend to be questioned by managers and that this has an adverse effect on implementation." It seems that as long as the model can provide tangible benefits over the existing system, it is bound to be implemented. Many IP problems have been solved using LP for the simple reason that the magnitude of the decision variables was high enough to justify rounding the value to the nearest integer - since it makes an insignificant change in the objective value ([Von Lanzenauer et al., 1987], [Bhatnagar, 1981]). Similarly, a superior solution (in terms of benefits) to an existing system has been obtained by assuming linearity or parameter values to be deterministic when, in fact, they were not.

Further, no evidence was found to support suggestions, such as that of Keen and Scott Morton (1978) that "strategic decisions being highly unstructured do not warrant analysis by quantitative methods" . On the contrary, this area is one of the most popular for MP. Even managers who believe that "real estate is an entrepreneurial business, which has little use for management science techniques at any level" implemented an IP application in the strategic planning of their real estate corporation, with a stated strategy of exploiting its quantitative capabilities for achieving a competitive advantage [Bean et al., 1987]. As a result of model implementation, they realized a gain in revenue to the tune of 40 million dollars.

3.7 - OPPORTUNITIES

OR tools have changed greatly computationally during the last few years as a result of advances in computer technology, but these improvements have not changed the formulation or solution processes of the problem, nor have we exploited the common computer literacy of end-users that could allow them to use OR tools independently. A survey of computer packages [Sharda, 1988] indicated that the tools and procedures that existed for mainframe computers have been made available on microcomputers without fully exploiting the microtechnology.

It seems feasible with the present computer technology to develop procedures for non-technical end-users, who then can use OR tools with ease and with little or no assistance from OR professionals. Such procedures may increase the extent and the frequency of use of OR techniques. In order to achieve this objective, one may have to develop a system that is compatible with the needs and abilities of people on the job, who may not possess the technical ability of an OR specialist. The effort needed to bring about improvements may only require extracting the good features of many different computer packages and combining them in one. If care is taken to ensure that every mechanical step (procedure) is automated, leaving bare essentials to the end-user, and if the procedure is designed with the user in mind rather than the OR professional, then it may be possible to see the MP technique being widely used by everyone in solving organizational problems.

4.0 - VISUAL INTERACTIVE MODELLING

4.1 - INTRODUCTION

Visual modelling has existed for centuries. One of the first models in the form of a data map was developed by Edmond Halley in 1686 [Tufte 1983]. Visual modelling became popular after CPM/PERT was introduced in the 1950s, and was well in practice in the 1960s [Donovan et al., 1969]. The interactive component was introduced as a result of advances in computer technology in the 1970s. With desktop computers and innovative software engineering, visual interactive modelling (VIM) today is a well established and widely used technique [Bell, 1992].

The concept of VIM has been very broad. It is recognized for what it does much more than for what it is. Bell (1986) defined it as the process of building and using a visual interactive (VI) model "to investigate issues important to decision makers." The definition is broad enough to fit all VI decision-making models, but VIM differentiates itself by insisting on the presence of three basic elements: a mathematical or symbolic model to represent the managerial situation, a visual display to present the status of the model, and interaction facilities for dialogue between the user and the model [Bell,1986].

The mathematical or symbolic model used in a VI system has been either an established technique like dynamic programming [Lembersky and Chi, 1984], or a custom-written routine as in a simulation routine (eg., [Hurrion, 1981], [Bell, et al., 1990]); a heuristic algorithm ([Shepard, 1983] cited in [Bell, 1985]); or an arithmetic relation [Chen, 1989]. The visual display can be in a representational form - usually a histogram, line plots, or a pie chart, or in iconic form - that is, a display of the system such as a Gantt chart [Jones, 1988], a map or architectural layout [Angehrn and Luthi, 1990], or a schematic picture of an object [Bell, Taseen, and Kirkpatrick, 1990]. The interaction in VI models has evolved over time with advancements in computer technology. The interaction ranges from a rudimentary start/stop and a restricted dialogue with the system to making changes in all aspects of the model, including model parameters and model structure, at any time before, during or after the model run.

VI models have been developed and are in use in many areas of managerial decision-making. The literature includes examples are used in production planning [Bowen, Fenton, Rogers, Hurrion and Secker, 1979], strategic planning [British Telecom, 1982], process planning [Bell et al., 1990], scheduling [Hurrion, 1978], [Bell, Hay and Liang, 1986], transportation [Kaufman and Hanani, 1981], [Kirkpatrick, Bell, 1989], hospital management [Jones and Hirst, 1986], cash management [Jack, 1985], [Parker, 1986], forecasting and many more areas.

Bell (1985 a, 1986, 1991) and Bell and O'Keefe (1987) provide an encyclopedic description of the past, present and future prospects of VIM. Some of the conspicuous features of their view are that VIM is about combining user-friendly interactive interfaces, computer-generated visual displays of model status, and mathematical or symbolic models of problems or processes into systems to aid decision-making. VIM's differentiation is on the insistence of a mathematical model that separates it physically from all other systems including MIS and CAD. Its distinctiveness is in its incorporation of a integral dynamic graphic interface [Parker, 1991]. Its uniqueness is in its delivery of synergetic effect using a three-element combination. In Hurrion's (1981) words:

> "If (an) end-user can watch a model progress then he is in a far better position to comment on its validity. Further, if the results do not agree with his intuition then a dynamic visual model can assist in explaining this difference. The end-user is also in a position where his practical knowledge of the real problem situation may be used to advantage, i.e, he may interact with the model and try alternative strategies" [Hurrion, 1981].

The results that agree with managerial intuition better facilitate implementation of decisions.

4.2 - VIM SOFTWARE

Building visual and interactive features takes much longer than coding the underlying mathematical model; therefore, it is mandatory to use standard software as much as possible [Anthonisse, Lenstra, Savelsbergh, 1988]. The software for VIM has come a long way from straight fourth-generation languages to object-oriented and interactive model building. Bell (1991), Parker (1991), and Chau (1992) describe chronological development of VIM software. As they note, generally VI software is more conducive to simulation and heuristics than any other technique. Some VI software that are available function as a graphical interface to a given OR-MS algorithm or function as an add-on to the spreadsheets. For example, MIMI/G is a graphical interface from Chesapeake Decision sciences Inc. for LP based problems and in particular production planning problems. Most recent spreadsheets (Microsoft Excell) has LP algorithm that helps solve problems in a spreadsheet environment. The VI software with preprogrammed algorithms of hard MS-OR techniques (such as LP, deterministic inventory or markov process) to be used for generic problems, and that can be used directly by non OR decision makers is not yet available, although general VI software allows user-written algorithms to be embedded.

The major difficulty in developing VI software with embedded MS-OR techniques seems to be that the developers eschew reinventing the wheel. The developers have to either code the technique on their own, or strike a joint venture with others who already have a perfected code. Insight International has introduced VI software INCEPTA as an interface to the mathematical programming code XPRESS-MP (from Dash Associates Ltd). INCEPTA is coded in GENETIK and is, therefore, compatible with the older versions of GENETIK (See Bell (1991) for a detailed description of GENETIK). INCEPTA seems to hold promise for VIM involving MS-OR techniques other than simulation.

There are many other possibilities as well where the current microtechnology can be exploited for VI modelling: for example Apple Computer's hypercard (see hypertext and hypermedia [Bieber and kimbrough, 1992]), or Microsoft's programming windows applications (see [Charles Petzold, 1992]). These alternative also appear equally promising.

4.3 - VIM METHODOLOGY

Visual interactive modelling methodology comes in many forms, and is sometimes referred to as visual interactive problem-solving (VIPS). Two extreme VI problem-solving processes have been proposed: passive and active (Bell, 1986). Passive VIM uses MS-OR methodology to enhance the likelihood of mathematical model implementation. The VI interface here assumes a secondary role to the development of the mathematical model. This "methodology is traditional MS-OR with a heavy reliance on the analyst to formulate the right problem and build the right model (and, perhaps, recommend the right solution)" [Bell, 1992]. The active VIM, on the other hand, exploits the VI features to impart effectiveness and efficiency to the problem solver. This methodology also helps in reconciling the differences in understanding of the problem between the analyst and the decision-maker. VI models developed using an active methodology use representational and iconic graphics that are usually dynamic - i.e., show the progress of the model. The visual display is not just a graphical display of the data concerned, but also contains what facts and how the decision-maker wants to see them when he is trying to make a decision.

VIM draws from both MS-OR and MIS, but the traditional approaches of both disciplines are unsuitable for it.

The MS-OR approach to modelling, given by Wagner (1969), is a four-step process:

1. Formulating the problem,
2. Building the model,
3. Performing the analysis, and
4. Implementing the model.

This modelling approach has been applied to countless numbers of problems, but is based on the assumption that the problem is structured, i.e., that it can be clearly defined, and that an objective function can be derived; therefore, it is unsuitable for VI-DSS.

Another MS-OR modelling approach to support complex problem-solving is computer-based Monte Carlo Simulation. For developing a simulation model, Shannon (1975) outlined the following stages:

1. System definition,
2. Model formulation,
3. Data preparation,
4. Model translation,
5. Validation,
6. Strategic planning,
7. Tactical planning,
8. Experimentation,
9. Interpretation,
10. Implementation, and
11. Documentation.

This process moves away from early formulation of the problem to defining the scope of the system, but remains a process for structured problems. The VI simulation builders use some of these steps but not necessarily in the same order.

On the other hand, MIS seems to have had a stronger impact on VI model building methodology. MIS had recognized a new generation of computer systems. Technology was "the factor" in this process, particularly on-line interactive computing. It operationalized the emphasis from solving structured problems to supporting unstructured problems. Early MIS project development was based on the System Development Life Cycle (SDLC) approach. Although there are many versions of this process [Turban, 1990], it is usually expressed in four phases:

1. Documentation and analysis of current system,
2. Logical and physical design of the proposed system,
4. Construction (programming) and testing, and
5. Implementation.

[Turban, 1990]

This process provides a good methodology for VIM, but only for "well structured situations where the problem or system is well understood, and the model can be usefully specified - a priori." [Bell, 1991]

DSS modellers with MIS background recognized a need for a departure from the traditional design strategy, and proposed methods labelled evolutionary [Keen, 1980], iterative [Sprague and Carlson, 1982], and prototyping [Henderson and Ingraham, 1982]. There are other names such as middle-out process, adoptive design, and incremental design, but the essence of these processes is similar. The four traditional activities of SDLC - analysis, design, construction and implementation - are combined in a single phase which is iteratively repeated in as-short-as-possible time periods [Sprague, 1980].

Motivation for this methodology seems to be that "most users do not actually know what they want until they 'feel' and see their system in operation" [Sprague and Carlson, 1982]. Once they have experienced the model, they can see different input and output aspects of their system. Visual interactive modellers have been using a similar methodology, but with some procedural changes depending upon the modelling experience of the modeller. Anthonisse, Lenstra, and Savelsbergh (1988) relate their experience that building interactive systems takes much longer than developing and coding the underlying mathematical algorithms. They say that "the time investment ratio is at least three to one." The iterative methodology pays little attention to this modelling difficulty. It is difficult for model-users to know if their suggestions for model refinements can be easily accommodated or need substantial model recoding [Hurrion, 1986]. Since it is difficult for modellers, and most of all users, to define in advance the functional requirements of the whole system while a module is under construction; they run a risk of repeated major overhauls of the system if not abandonment of the project altogether. VI modellers have synthesized their experience with ideas coming from MIS and MS-OR to propose three essential steps before programming and testing. They are:

1. Screen development,
2. Interface development, and
3. Algorithm development.
4. Construction (programming) and testing, and
5. Implementation.

(See for eg. [Bell and Parker, 1985], [Parker, 1986])

In the first step, the decision maker(s) and the analyst begin a interactive joint problem solving-process. The decision-maker(s)/user(s) are asked to present the information they want to have for making the decision, and how (display) they prefer to see it on the screen. This information is laid out on paper using coloured pens. "Laying out screen displays on paper which show the process, the control variables for the problem, and the model outputs or performance measures leads the decision-maker into playing a leading role in problem formulation, improves his/her understanding of the problem or process, ... all before a single line of code is written" [Bell, 1992]. This step stems from the attention paid to how the user wants to use the model, as opposed to how he must use the model [Bell, 1985]. The screens, though imaginary, could be static or dynamic (animated) in representational or iconic form, and could represent the system-input or the system-output. On these screens the modeller builds the next steps -- thinking about the kind of interface to provide, and about the required algorithms to achieve the screens.

The next step is to transfer the paper model to the computer, including the mathematical algorithm and the interface required to derive the model. Since the decision-maker is already familiar with the content and the form of the information in the model, the following steps are accomplished efficiently, including implementation.

4.4 - VIM AS A DECISION SUPPORT SYSTEM

After about fifteen years of refinement in methodology and progress in modelling, VIM is becoming a well-established technique in MS-OR. In an article by ten renowned MS-OR professionals,[2] the problem-solving process has been described as fixing agendas, setting goals, and designing actions, and decision-making has been defined as evaluating and choosing. In that sense, VIM has gone beyond the problem solving approach (the VIPS approach) of the initial period, and now it seems to be a well-entrenched decision-making tool.

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[2] Simon, Dantzig, Hogarth, Plott, Raiffa, Schelling, Shepsle, Thaler, Tversky and Winter, (1987).

The major contribution that VIM has had, and probably will continue to have, is its ability to improve the communications and language barriers that exist among the modeller, the user, and the system [Hurrion, 1986]. Hurrion (1986) further stated that the (VIM) "technique has become transparent; it is no longer regarded as 'black-box'." The visual display and interaction, the two integral elements of VIM, are responsible for this transparency. Interaction copes with the tradeoffs between multiple optimality criteria -- those that are not explicitly known but are carried implicitly in the value judgement of the decision-maker [Fisher, 1986]. The visual display helps in the process by permitting a quick assessment and analysis of the data being presented [Anthonisse, Lenstra, and Savelsbergh, 1988]. In Hurrion's words, "having a dynamic animated view of the model ensures that the client commissioning the original study can observe the model in the form of a 'video' film" [Hurrion, 1986], while in a static presentation "it is impossible to convey adequately the degree of impact obtainable by showing a moving, coloured, representation of the process being modelled" [Everett, 1984 cited in Bell, 1986].

There are examples where VIM was used as an alternative when the models built using conventional methodology failed to convince the clients about the authenticity of the model results. Gravel and Price (1991) developed a VI simulation that allowed them to show the managers of a small clothing plant how the Kanban method could help them, to persuade them to accept it, and to support its implementation. They had to build the

VI simulation when a nonvisual simulation did not convince the managers of the potential benefits of the Kanban method that could be obtained in a small clothing plant.

Kirkpatrick and Bell (1989) conducted a survey of VI model builders and reported that 14 percent of the respondents said that the graphics component enhanced their understanding of various aspects of the problem or the mathematical techniques "incredibly", while 43 percent said "greatly" and 33 percent said "moderately".

Despite this promise of VIM, DSS literature in MIS has not formally recognized this approach. The basic problem is that "the existence of dynamic iconic display has not yet been recognized by MIS researchers" [Bell, 1991]. Though VIM is unique in its own right, the DSS generated have a lot in common with the DSS coming from MIS or any other perspective. The essential aspect is the goal - they are all built to support managerial decision making. VIM, then, offers a novel problem solving-approach that has existed exclusively in the realm of MS-OR in spite of being a hybrid of MS-OR and MIS [Parker, 1986].

4.5 - EMPIRICAL RESEARCH IN VIM

Although VI models hold much promise as DSS, they have to contend with research problems commonly encountered in DSS practice. A major problem is that hard evidence on the effectiveness of VIM in a DSS does not exist. Since the majority of VIM applications were and continue to be simulation-oriented, the question of whether computerized simulation models are good or bad does not arise, because obviously manual simulation models are not a match. However, the effects of decision aids in VIM were and are contentious, just as they are in DSS. In particular, the value of the visual displays is questioned.

4.5.1 - VALUE OF GRAPHICS:

A number of studies have been conducted on the effect of the graphical display of information on decision making, yet, a preliminary survey indicates that the results are inconclusive. DeSanctis (1984) conducted a comprehensive survey of graphics research and analyzed the reasons for such equivocal results. She writes that graphics have been of interest in many disciplines and have been looked at from varying perspectives by statisticians, human factor engineers, cartographers, psychologists, audiovisual and communication educationalists, and marketers. At least twenty studies have been conducted by these researchers to determine the quality of graphics in terms of effectiveness when compared to tabular data. The quality was measured using dependent variables that include problem-solving (speed and accuracy), interpretation (speed and accuracy), decision (speed, quality, and accuracy), comprehension, recognition and recall, and viewer preference. There is no common agreement, however, regarding what should be studied and no formal discussion of the rationale for choosing particular variables [DeSanctis, 1984]. The following table summarizes the results of these studies. Obviously, the conclusion drawn was that the superiority of either tables or graphics was inconclusive.

Summary of Research Results comparing Graphs and Tables for Selected Dependent variables[a]

Dependent Variable	Better with Graphs	Better with Tables	No Difference
Interpretation accuracy	2	4	1
Interpretation speed	1	1	-
Decision making or problem-solving quality	1	3	3
Decision-making or problem-solving speed	1	1	2
Information recall	-	-	2
Preference	2	2	-
Decision-making confidence	-	1	2
	-----	-----	-----
Total	7	12	10

[a] Numbers indicate number of studies for a given category

Table - 4.1: Previous studies regarding the superiority of graphics versus tables.
Source: DeSanctis (1984), P-475

After this survey, at least five more empirical studies measured the effect of graphic and tabular formats. Remus (1984), Benbasat, Dexter, and Todd (1986), and Liang (1986) concluded that tabular presentations were better than graphical presentations. Other studies indicated that presentation formats influenced information acquisition strategies and evaluation strategies [Jarvenpaa, 1989], and that the influence of presentation formats depended on the task characteristics [Dickson, DeSanctis, and McBride 1986]

There exists evidence that graphics are better for some tasks such as trend recognition, and tables are better for the determination of precise numbers (see [Dickson et al., 1986], and [Jarvenpaa, 1989]). Despite this evidence and lack of agreement on choosing dependent variables, it seems that most researchers have tried (at least implicitly) to study the *universality* of graphical superiority or inferiority, instead of matching them with problem type, or identifying the area of suitability for a given format.

There is also evidence that attributes such as size, shape, brightness, contrast, blinking, colour, texture, paper, and screen change the characteristics of a graph. Yet there is no attempt in any of the above studies to differentiate one graphic type from another, except for identifying line graphs, bar graphs and circle (pie) graphs. Cleveland and McGill (1984, 1985) conducted experiments to show how accurately different encoding schemes (data representations) are perceived. They encoded data as the size of an angle, the brightness of a color, the length of a lines, or the position of points along a common scale, among others. They found that data encoded as a position along a common scale is most accurately perceived and angle size is less accurately perceived. This implies that pie charts where data is encoded as the size of an angle, are less accurately perceived than bar charts.

In visual interactive modelling, Bell (1985, 1986) has identified four different kinds of graphics that are available.

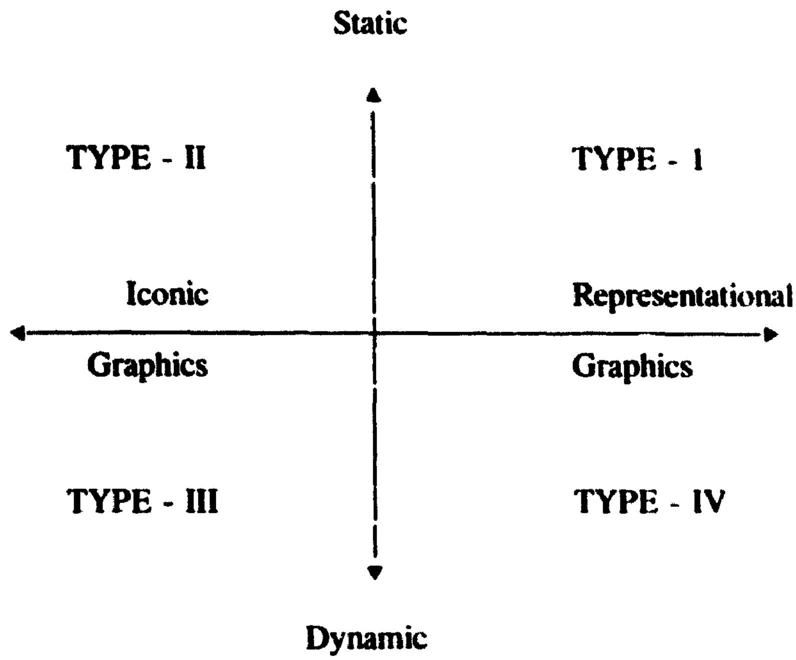

Figure - 2.2: Four types of graphics.

As seen in Figure - 2.2, the VIM graphics can fall in one of four quadrants. The majority of graphics fall into the first quadrant (type - I), these include all the business graphics (line, bar and circle (pie) charts). Ironically, most of the research is limited to this kind of graphics . As far as VIM is concerned, the graphics that fall in the first and second quadrants (type-I and type-II) are used in the input or output display at the beginning or at the end of the model run, while the third and fourth quadrant graphics are displayed during the model run, and usually in simulation models.

Empirical studies on the effect or usefulness of type-III and type-IV graphics are almost nonexistent. Studies on the type-II graphics are too limited to draw generalized conclusions, although they have so far indicated positive results. In the marketing and accounting literature, iconic graphics in the form of faces and cartoons are being developed to represent multivariate data, i.e., data characterised by five, ten or more dimensions (see [Chernoff, 1973]). Huff, Mahajan, and Black (1981) used a series of faces to display the values of eleven key financial variables for different firms over a period of five years. By assigning variables to features and equating a happy face with a good financial position, they demonstrated in a non-empirical study how faces can provide a quick indication of the relationships between variables.

In an experimental study, Moriarity (1979) deait with financial data for 22 firms over a six-year period. Subjects were exposed to data in tabular and facial formats and were asked to indicate whether the firms went bankrupt or stayed solvent. Moriarity concluded, by measuring the task by the number of errors made using the tabular and facial formats, that the subjects were able to make significantly better predictions based on facial formats.

In a similar study by Stock and Watson (1984), subjects were asked to predict the corporate bond rating of firms, based on tabular and graphical displays of financial information. The subjects were classified according to their level of accounting training and results showed improved performance with graphical displays at all levels of training. In a later study by MacKay and Villarreal (1987), attractive properties of facial displays were found. The significant differences in task performance were found to be related to the perception of the holistic manner of facial display and the particularistic (item-by-item) manner of tabular display. MacKay and Villarreal (1987), however, indicated that even though graphic displays are more holistic than tabular displays, graphics do not necessarily facilitate more accurate decision-making.

It would seem that future results will continue to show contradictions as in the past, unless some task taxonomy is developed [Jarvenpaa et al., 1985]. The mixed results in task performance with graphic and tabular displays demonstrate the need to study conditions under which one display will outperform others, instead of proving (or disproving) the universal superiority of one over the other [DeSanctis, 1984]

4.5.2 - COGNITIVE EFFECT:

While certain authors view task complexity to be an important characteristic in the process of decision-making, many others view cognitive effect as a related, but equally important, factor in decision-making. "Cognition refers to the activities involved in attempts by individuals to resolve inconsistencies between an internalized conceptualization of the environment and what is perceived to be actually transpiring in the environment" [Zmud 1979].

The proponents attribute the graph versus table controversy to individual differences in the cognitive style of decision-makers [Davis and Elnicki, 1984]. They state that human beings are limited in memory and processing capability. Therefore, if we discover the limitation in cognition, we will have the elements to support a computer-based decision system [Zmud, 1979]. Managers need information geared to their own psychology, not to that of their designers [Mason and Mitroff, 1973]. There are authors who do not oppose the idea of cognition, but contend that while developing the system, one must model the problem not the decision-maker.

Of the numerous factors believed to influence MIS success, the area of individual difference has been by far the most extensively studied [Zmud, 1979]; yet the empirical studies show no apparent conclusion, although its importance is being increasingly recognized. In studies conducted to examine the effect of a decision-maker's cognitive type on performance, Benbasat and Schroeder (1977), Lusk and Kersnick (1979), Lucas and Nielson (1980), Benbasat and Dexter (1982), and Davis and Elnicki (1984) found significant relationships, and support for the theory that high analytics perform better with data, while low analytics perform better with graphics. On the other hand, Henderson and Nutt (1980) found significant relationships showing that high analytics perform better with graphics, while low analytics perform better with data.

Barkin and Dickson (1977), and Alavi and Henderson (1981) did not find significant relationships between cognitive types and performance, but did find significant relationships between cognitive types and system utilization. O'Keefe and Pitt (1988), in their experiment with a VI simulation model uncovered no significant findings, but found some support to the theory. Low analytics preferred graphics and high analytics preferred animation.

Vessey (1991) conducted an inductive analysis on the results of published studies that examined the performance of graphical and tabular representations in decision making. Based on information processing theory, she presented a "Cognitive fit" theory to explain under what circumstances one representation outperforms the other. The fundamental aspects of her theory are as follows:

1. Although graphical and tabular representations may contain the same information, they present the information in fundamentally different ways; graphical representations emphasize spatial information, while tables emphasize symbolic information

2. Tasks can be divided into two types, spatial and symbolic based on the type of information that facilitates their solution.

3. Performance on a task will be enhanced when there is a cognitive fit (match) between the information emphasized in the representation type and that required by that task type.

4. The processes or strategies problem solvers use are identified as of two types, perceptual and analytical. The processes are the crucial elements of cognitive fit since they provide the link between representation and task.

5. If there is a complete fit of representation, processes, and task types, each representation will lead to both <u>quicker and more accurate</u> problem solving.

   [Vessey, 1991]

Vessey's "cognitive fit" theory seems to be more comprehensive and may be used to explain the contradictory results obtained by a number of researchers while testing the information systems theory that high analytics perform better with data and low analytics perform better with graphs.

In reviewing the implications of cognitive effect on MS-OR, O'Keefe (1989) advised awareness of the cognitive fit, and cautioned with at least three criticisms that Huber (1983) had made earlier: that

1. Three different instruments were used by these researchers to measure cognitive types and cognitive fit (Myers-Briggs type indicator (MBTI), Embedded Figures Test (EFT), and WCFAFT developed by University of Minnesota MIS department). The MBTI is said to be 'the best of an admittedly weak set of

instruments' [Zmud, 1979]. Therefore, the reliability and validity are questionable.

2. Almost all tests were conducted in a laboratory setting using students. How far the results can be generalized is debatable.

3. Many of the tasks performed by subjects are either simple, or very structured, therefore implying again a conservative extrapolation of results.

[O'Keefe, 1989]

4.6 - NEED FOR FURTHER RESEARCH:

The literature shows a number of areas where more research is warranted in order to establish the credibility and popularity of VIM. Most of the areas have been clearly identified in Bell (1986 and 1991). Some of them are as follows:

1. The majority of VIM applications are in the manufacturing field; it is necessary to broaden the base in other areas. Applications of VIM in industrial sectors such as services, resources, and communication, and functional areas such as

marketing and finance are particularly limited. Also, applications where structure in the problem is a little elusive may add value to the VIM.

2. The majority of the VI models are stand-alone models, often designed by the user him/herself to address a specific, one-time issue. There are very few operational models for continuous use. Such operational models, in addition to broadening the base, may shed some light on a different user-designer relationship with which current VIM has had little experience.

3. There is some theoretical support for the usefulness of a VIM, but proponents have been less than modest in expressing their experience. Despite VIS being the largest body of VI models, O'Keefe and Pitt (1991) write that the "majority of what we know is *folklore:* largely experiential and anecdotal, and not backed up by strong empirical evidence." More empirical tests are required.

4. In the general literature there is no resolution or conclusion regarding the value of graphical versus tabular display. It has been suggested in the MIS literature that only certain types of tasks and certain types of decision-makers find graphics useful. Since VIM generates various and different kinds of graphics, it has to develop and prove its own case.

These research areas are fundamental in nature. It seems imperative that these areas should be investigated if VIM is to serve as an established technique for supporting decision-making and for exploiting ever-advancing computer technology to its full potential.

5.0 - RESEARCH OBJECTIVES AND RESEARCH METHODS

5.1 - RESEARCH OBJECTIVES

The preceding literature review raised many research questions, but to limit the scope of this research, the following were addressed in this study.

The DSS classification in the input-output-process framework revealed a conceptual difficulty with applications of mathematical programming titled DSS. It was argued that the input (considered to be the only known parameter in the sixth type of DSS) is usually not known with certainty. If it were known, then a DSS would not be required -- the mathematical program alone would give a prescriptive solution to the problem. If it is assumed that the inputs are uncertain, which appears to be a realistic assumption for many real world problems, then the role of MP is limited and can be questioned. The surveyed application papers with MP were not found to distinguish the DSS from a purely normative technique, and no attempt to justify the title was found.

The literature on the applications of MP revealed the importance of user-model communication. Many modellers have moved away from using MP because of a lack of tools to help communicate the mathematical nature of the technique in simple terms [Aggarwal, 1990]. It was noted by Lockett (1985) that with the current MP software it is too easy to lose sight of the real purpose, which is, in the words of Geoffrion (1976), to provide insight and not numbers. Most of the software is traditional and does not allow more than minimal custom-written rudimentary interaction. The difficulty for the modeller is to formulate a problem to fit the available software, and to present the sc .ion in whatever form the software allows.

The literature in visual interactive modelling (VIM) provided theoretical, some empirical, and overwhelming experiential support for improved user-model communication. The literature in VIM also suggested that there was a shortage of operational VI-MP models. Therefore, building a visual interactive linear programming (VILP) model as a VI-DSS was taken as the first objective of this thesis. The aim was to build an improved DSS that was free from the modelling difficulties and the user-model communication difficulties commonly encountered in the MP applications. i.e.:

1. Build a decision support system that:

   a) addresses a fairly common semistructured problem;
   b) includes mathematical programming in its model base;
   c) expects no knowledge of mathematical programming from its user;
   d) presents information in iconic displays for managerial decision making;
   e) displays an "optimum" solution as the starting point for further managerial analysis; and
   f) uses a visual interactive methodology for building the model.

The second objective was to test empirically the performance of the VI-DSS having iconic visual displays with another DSS built to address the same situation, but having the information in tabular displays. The specific tests to be conducted centered on the following issue:

2. The VI-DSS should lead to a more "effective" managerial performance than the non-VI-DSS. Since the only difference between the two DSS was the display of information, the claim was also made that the iconic graphics better assist managerial decision-making than the tabular display. The following were the four main postulates that were tested:

    a. VI-DSS users make more effective decisions.
    b. VI-DSS supports better and more effective learning.
    c. VI-DSS users avoid extreme decision options.
    d. VI-DSS is a more efficient decision making system.

5.2 - RESEARCH METHOD - THE MODEL

5.2.1 - DECISION SITUATION

Bell (1991) indicated that there was a high cost associated with developing VI models, leading to an incentive to try to build application specific generic models that can be used for several studies. The survey of DSS applications revealed that the sales forecasting of products with a high risk of market obsolescence was a common semistructured problem, for example, fashion, seasonal, and novelty products [Bush and Cooper, 1988] or fish processing [Jensson, 1988]. Therefore, a sales forecasting problem concerning a publishing firm was selected for DSS model building.

5.2.2 - THE PROBLEM

The problem is described in the case MK Publishing Inc. (Appendix - 8.1). Briefly, the problem concerns a large publishing company which publishes six weekly magazines. The company prints the magazines in its own press-shop, which reserves press and collator time each week in advance. The publisher must decide the required number of copies of each title to print, every week, before the manuscripts are sent to the press shop. Historical newsstand sales provide the best available estimate of future sales. The sales and quantity printed each week generally depend on other issues as well, which may be magazine content, newsstand display, and advertising commitment (publishers must print the minimum quantity committed to the advertisers).

The managerial problem is to decide the number of copies of each title to print in order to best utilize the reserved press time, and to provide maximum contribution to the company. The cost of the press time is a sunk cost to the publishing firm; therefore, they allocate available capacity to titles without exceeding the time limit. The quantity printed in excess of actual sales is brought back and destroyed at the publisher's expense (about 25% of the newsstand price including paper,ink, and processing cost). Stockouts, on the other hand, lead to loss of potential sales and also affect future sales. Therefore, the recommended quantity should take into consideration the printing capacity, and the possibility of returns and stockouts.

5.2.3 - MODEL DEVELOPMENT

Model development started in mid-June 1992 with the help of two PhD students, who were asked to read the case and act as "decision makers". Initial discussions with them concerned the issues in the case and a possible solution methodology to pursue. Based on the case and discussion a prototype was developed on paper. The prototype contained the information that would be required to solve the problem in the case. The prototype was designed from the analyst's point of view; therefore, the "decision-makers" were asked to provide comments and input to the content and display format. After the review, the "decision-makers" felt that the information in the model was adequate, but wanted some changes to the format. They also preferred to have some static data on the screen instead of referring to it from the case.

After making the required changes in the displays, the model was redrawn on paper. Initially, all the displays were intended to be presented on the same screen, but when the displays were redrawn on screen-size paper, they turned out either too small to be useful or illegible. Displays were then adjusted in their layout and size after the realization that the required information including the display of the process, the control variables for the problem, and output or performance measures required at least two screens.

The next step was to transfer the paper model to the computer, including the interaction routines and algorithms to drive the displays. GENETIK, which has been successfully used by many for coding VI models, became the choice for this model. Because of lack of previous experience with GENETIK, about two weeks were spent learning the software. It became increasingly clear that GENETIK could be used to draw displays and provide interactive facilities, but coding mathematical programming or developing an interface to use an external MP code was not easy. Fortunately, Insight International had developed INCEPTA, an interface for using XPRESS-MP (the MP software from Dash Associates). The interface was acquired in August and coding began after a week was spent learning the basics of INCEPTA and XPRESS-MP.

INCEPTA was used to code the visual displays and interaction routines, and XPRESS-MP to provide the mathematical programming code to the model. XPRESS-MP takes the problem formulation in MPS format; therefore, the formulation had to be converted from LINDO format, which had been initially coded. The display and interaction routines were first coded using dummy data, then interface routines were coded to connect INCEPTA with XPRESS-MP. After the successful interface, actual XPRESS-MP data were used to test and validate the displays.

The basic model was ready by early September. The model was presented to the "decision-makers" for comments and feedback. Their initial reaction was positive, but when they started tackling the issues in the case they felt very strongly that information on the magazine returns was at best poor. During their trial, it was also noted that the display of some static data was prone to misinterpretation. As a result, the displays were modified and new information was added. The resulting model was found to be satisfactory by the "decision makers".

With the model construction, model validation was also carried out simultaneously. In addition to the "decision-makers". input was sought from a manager of a publishing firm and a manager of a printing press in order to ensure model authenticity.

The main difficulty in model validation was the limitation imposed by the available technology to duplicate the paper model on the screen. The screen-size (roughly half of an eight-and-a-half by eleven page) presented a problem in offering user-described realistic displays. Since the main purpose of the DSS was effectiveness, some realism was inevitably sacrificed. The returns estimate presented on the screen was based on a linear approximation of the actual expected value. (See [Bell, 1981]) (A comparison of actual and approximate values is shown in Appendix - 8.7) The estimates were validated by simulating the process for each title.

After the visual interactive DSS was built satisfactorily, another DSS was built to address the same situation. The only difference between the two DSS was the display format. In the second (non-VI-DSS) DSS, tabular displays instead of visual displays were provided, and as much as possible the same code was utilized to maintain model validity

5.2.4 - MODEL DESCRIPTION

The VI-DSS consists of two symbolic/ mathematical models and five visual displays presented on two computer screens. The six magazines are represented with different colour codes in the DSS, i.e. one colour for each title, and are consistently used in all displays. Four displays are shown on the first screen (main screen) and the fifth display, concerning historical information is shown on the second screen. The DSS performs four functions: change print-quantity, display new solution, show historical information, and finish the session -- i.e. Quit without saving any changes made during the session, or Exit by saving the session results. The functions are executed by clicking any mouse button on the required menu-item that is displayed on the menu-bar as shown in Figure - 5.1.

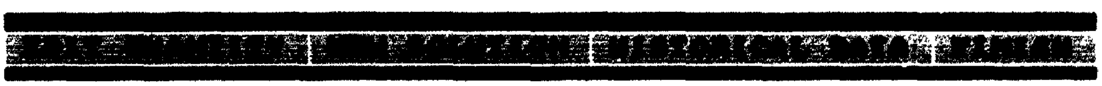

Figure - 5.1: DSS menu

When a user starts the session, the main screen is displayed with the first four displays. Should the user desire to see the fifth display, concerning historical data, then clicking on the menu item "Historical Data" will result in the DSS presenting the second screen having the fifth display. In order to return to the main screen "Exit" from the second screen menu must be selected. Exiting or quitting the session is done from the main screen only.

As noted above, the main screen of the DSS consists of four displays. The first display shows the demand distribution and the "actual" print-quantity numerically as well as graphically (Figure - 5.2.)

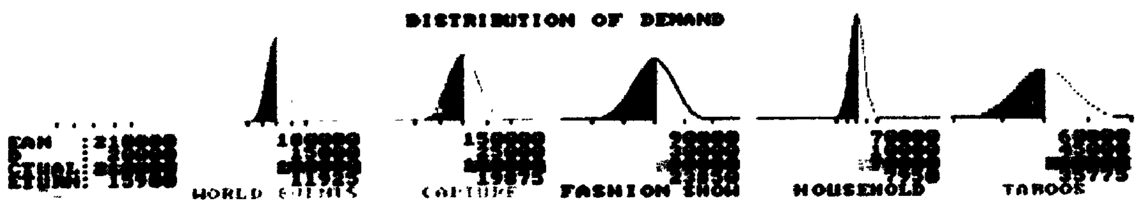

Figure - 5.2: Distribution of demand for each title (Display # 1)

If the user wishes to edit the "actual" quantity, i.e. select/change print quantity for any title, then clicking the mouse on the menu-item "Edit Quantity" (Figure - 5.1) and changing the "Actual" quantity (Figure - 5.2), by overwriting the previously displayed value, accomplishes the task. As a result of overwriting, the new value is displayed in its own colour code instead of the black colour used originally. The colour change indicates that the user has changed the input parameters and the information on the screen needs updating. After changing the quantity to a new value, the information can be updated by clicking the left mouse button first to get out of the editing mode, and then clicking (any button) on the "New Solution".

On selecting "New Solution", the model creates a new mixed-integer programming (MIP) formulation based on the print-quantities selected, and solves for an optimum utilization of presses and collator. (A sample MIP formulation for the initial condition is provided in the Appendix - 8.8). The MIP solution prescribes the allocation of titles to the printing presses, determines the sequence and calculates the print duration for each title, and calculates the total contribution for the selected print-quantities.

The first display shows the demand distribution of each title. This display allows the selection of the number of copies of each title to be printed, together with static information such as mean and standard deviation of the demand-distribution for each title, and also dynamic[3] information such as the "actual" print-quantity selected by the user and the expected number of "return" copies.

The expected return-quantity for each title was estimated, following the procedure derived by Bell (1981), by five piece-wise linear equations to approximate the curve. (See Appendix - 8.7 for derivation and a comparison of actual and approximate values of the returns.)

The second display in the DSS shows the utilization of presses and the collator graphically. The graphic information includes the allocation of titles to presses, the

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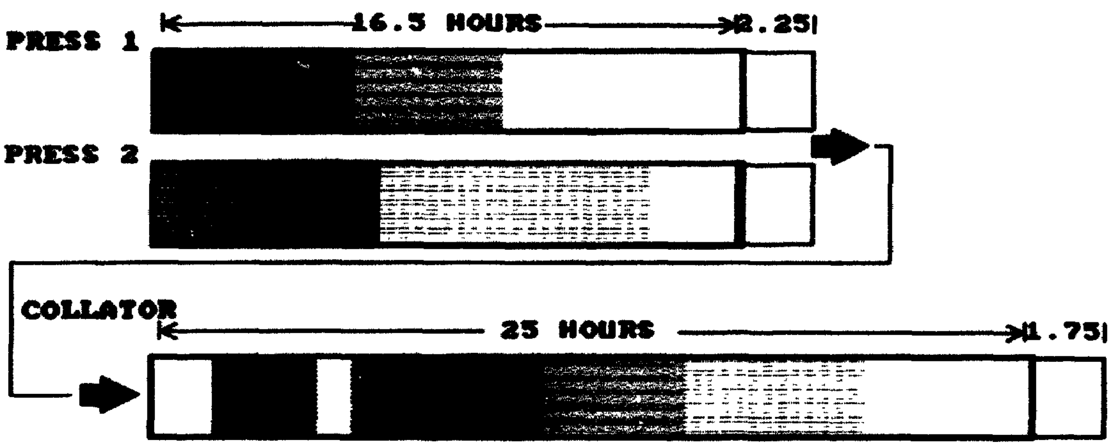
[3] - > The display changes with each iteration, but is not "dynamic" in the sense that animation is dynamic.

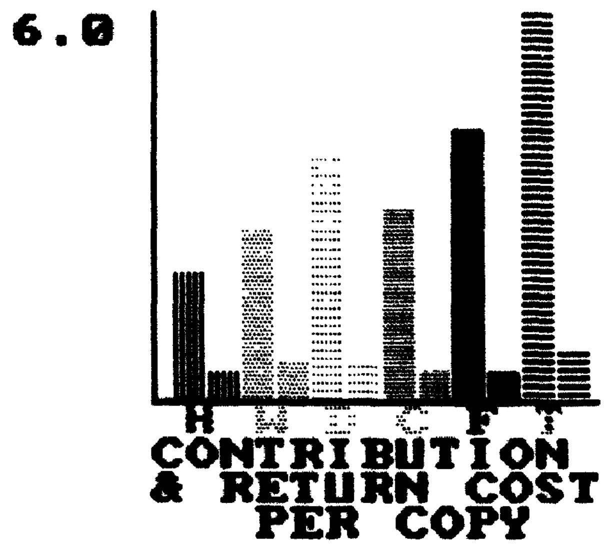
sequence in which they will be printed and print-duration of each title, as shown in Figure - 5.3 (A shade or colour represents a title in the display).



Legend: A shade represents a title
Figure - 5.3: Assignment of titles to presses and collator (DSS 1 display #2)

This display also indicates if the machines (presses and collator) are idle at any time during the reserved period, or if they are working overtime. For utilizing the machine capacity differently, the user must change the quantity of any (or all) title(s). The DSS will estimate the new optimum assignment and printing schedule to reflect the new quantities.

The third display, shown in figure 5.4, is a static graph of the information concerning contribution and the return cost per copy of each title.



Legend: A shade represents a title
Figure - 5.4: Contribution per copy & return cost per copy for each title (DSS 1, display #3)

The display shows the relative difference between the contribution made by a copy of a given title when sold and the cost incurred if the copy is returned back for lack of demand. This information, concerning the relative difference, can be used to prioritize the title selection and print-quantity so that the marginal contribution is maximized for the available machines capacities. This display is static and does not change from one trial to the next.

The fourth display (Figure - 5.5) gives the revenue (after printing cost) if the quantities selected by the user are all sold. This display also shows the net expected contribution and the expected "returns" cost. The display is as shown in Figure - 5.5.

REVENUE After Printing	:	$ 2428400
EXPECTED RETURN COST	:	$ 51715
EXPECTED NET CONTRIBUTION	:	$ 1959191

Figure - 5.5: Data summary (DSS 1, display # 4)

The fifth display is a graph of net contribution and the print quantities of each title. All the graphs (six for print quantities and one for the expected contribution) are superimposed on a single display and presented on the second computer screen (Figure - 5.6).

This display shows, graphically as well as numerically, the contribution and the print-quantity of each title selected. The numerical information is however shown for only one trial (iteration) at a time, starting with the last trial by default. If the numeric information for any other trial is desired then it can be displayed on the screen by simply clicking on the menu item "Change trial #" and then on either left arrows or right arrows provided adjacent to the white box at the top right corner of the screen. By clicking on the left or right arrows the numeric information changes to the next or previous trial. If information concerning a specific trial is desired then a click on the displayed number (trial #) in the centre of the box, and overwriting the desired trial number achieves the result.

Figure - 5.6 and Figure - 5.7, show the second and the first (main) screens with the integrated displays respectively in colour.

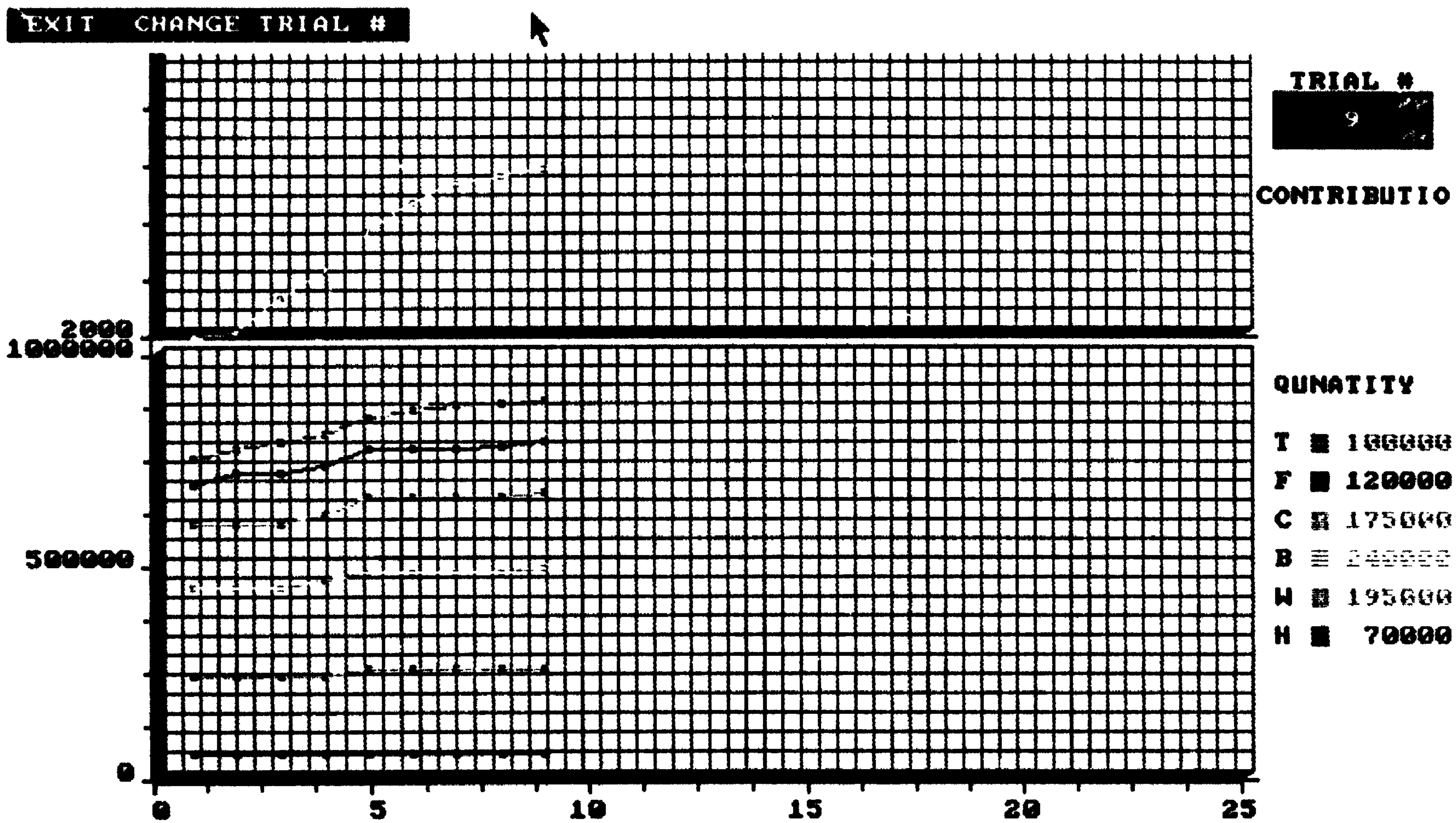


Figure - 5.6: Screen 2 of DSS 1

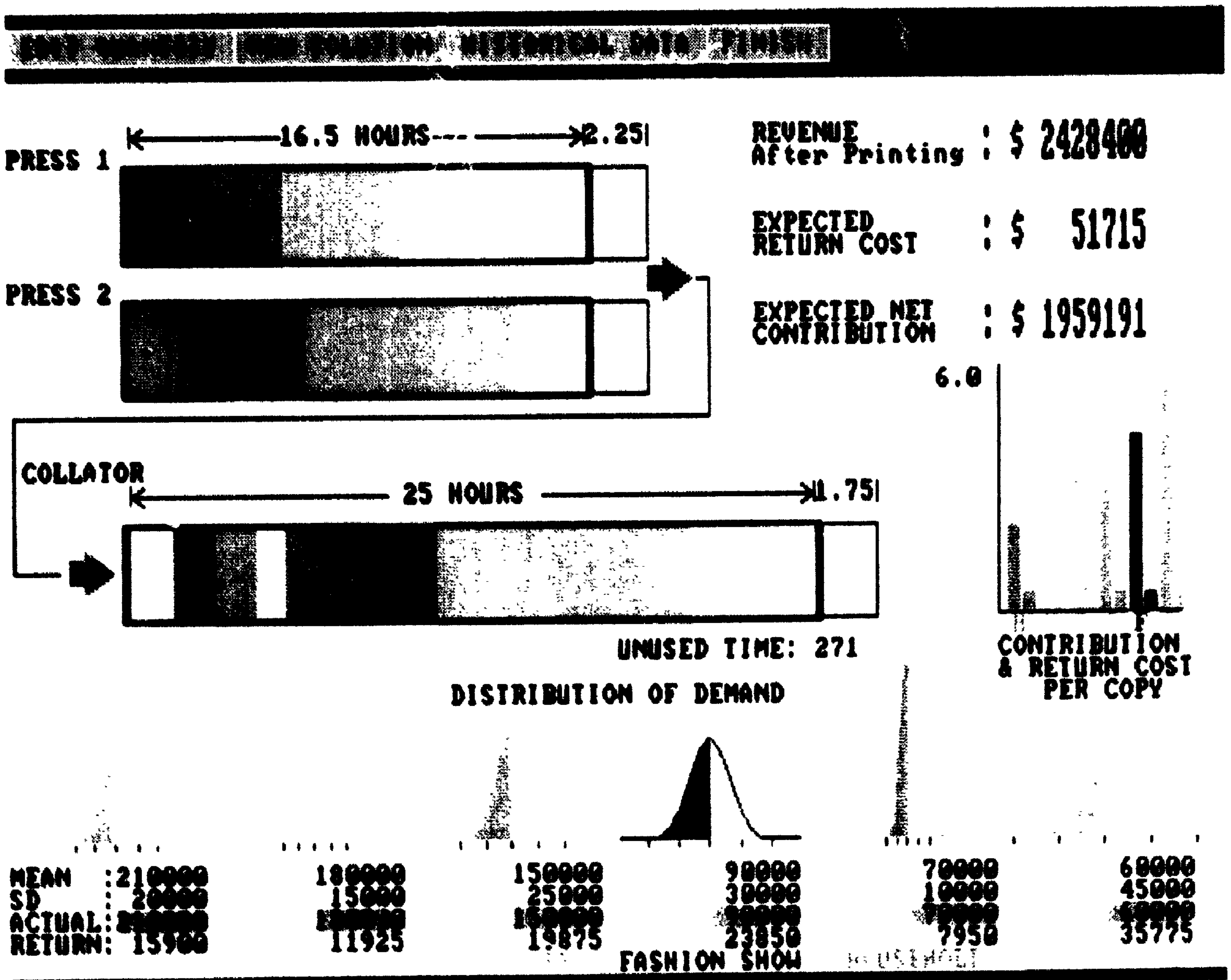


Figure - 5.7: Screen 1 (Main Screen) of DSS 1

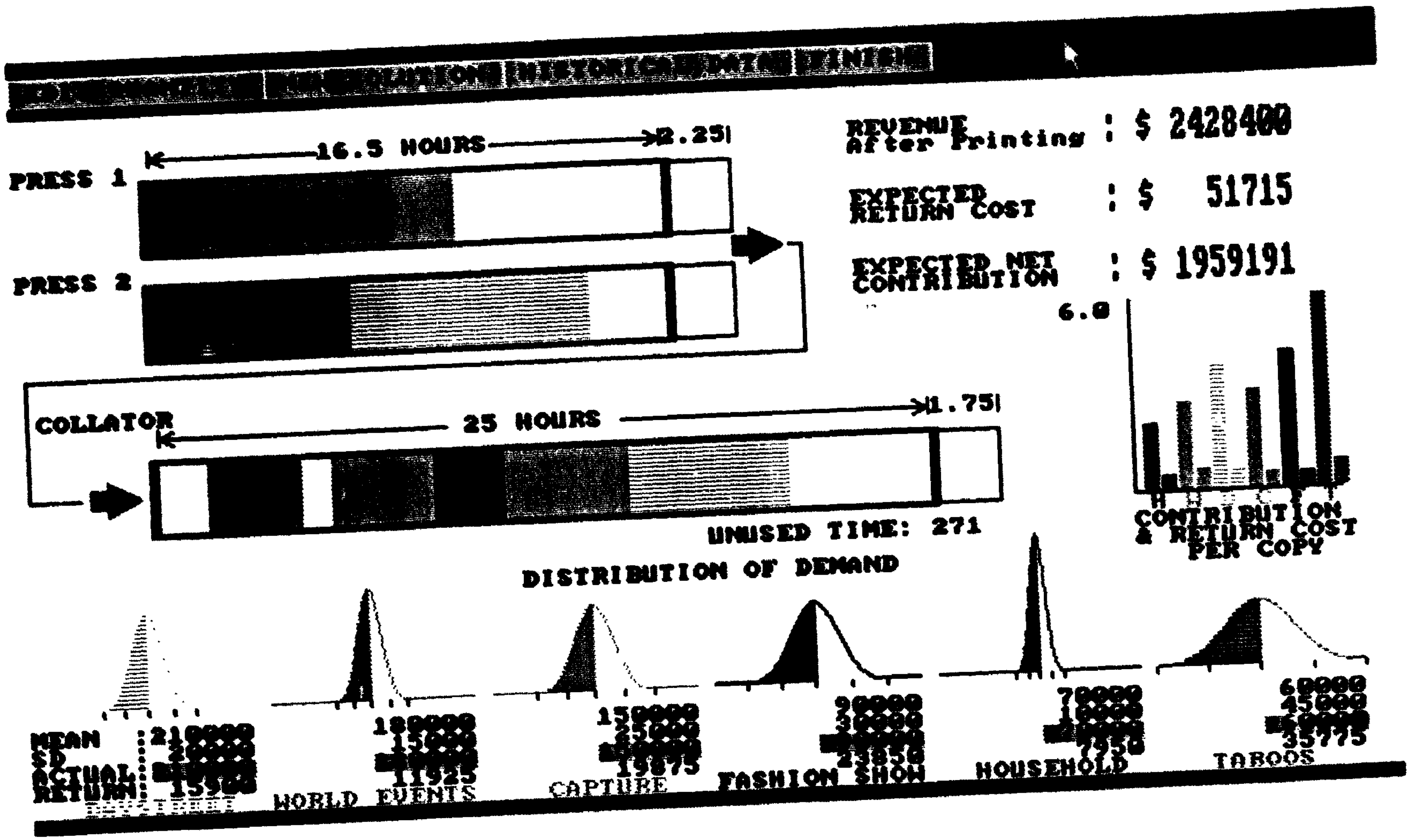


Figure - 5.7: Screen 1 (Main Screen) of DSS 1

The second DSS (DSS 2) is quite similar to the first one in its operation. The menus, functions, and procedure to use the DSS are exactly the same as the first DSS (DSS 1). DSS 2 also consists of the same five displays as in DSS 1, the difference however is in the display format. In DSS 2 the information is provided numerically and in tables. The same colour code, as in DSS 1, is maintained for easy title recognition. The first and the fourth display in DSS 2 are similar in DSS 1 (Figures 5.2 and 5.5). The information contained in them are already in numerics. The other displays are, however, different and are described below.

The second display concerns the presses and the collator utilization. This display is as shown in Figure - 5.8.

PRESS & COLLATOR UTILIZATION (IN MINUTES)									
TITLES	PRESS 1			PRESS 2			COLLATOR		
	BEG.	END	DUR	BEG.	END	DUR	BEG.	END	DUR
HOUSEHOLD	0	95	95	—	—	—	96	189	93
TABOOS	—	—		0	156	156	189	279	[illegible]
CAPTURE	95	[illegible]	[illegible]				[illegible]	[illegible]	[illegible]
FASHION SHOW	—	—	—	156	381	225	539	674	135
WORLD EVENTS	339	[illegible]	[illegible]				[illegible]	[illegible]	[illegible]
DAY STREET	—	-	-						
UNUSED TIME	404			152			271		
OVER USED TM	—			—			—		

Figure - 5.8: Assignment of titles to presses and Collator (DSS 2, display # 2)

This display provides beginning time, ending time and duration for printing of each title on each press. Similar information for collation is also provided. At the bottom of the table unused-time or overtime used for each machine is provided. The order in which the titles are listed in the table gives the sequence in which the titles will be printed or collated.

The third display is the static information about the contribution and the return cost per copy of each title. This information is provided in a table of two columns as shown in Figure - 5.9.

CONT. & COST/COPY IN $$	
CONTRIBUTION IF SOLD	COST IF RETURNED
1.99	0.36
[illegible]	0.55
[illegible]	0.43
4.02	0.33
[illegible]	[illegible]
[illegible]	[illegible]

Figure - 5.9: Contribution per copy and return cost per copy for each title (DSS 2, display # 3)

In this display the information remains static but the order of list changes with change in the order list of the second display. (See the full screen in Figure - 5.10)

The fifth display contains the information about the contribution and print quantity as in the fifth display of DSS 1. In DSS 2, the information is provided numerically in tabular format. The display is shown in Figure - 5.1

This display has only seven columns of information because of the limited screen size. The procedure to display and see the information on previous trials is however not affected by the screen size, and is the same as in DSS 1.

The first and the second screen of DSS 2 is shown in Figure - 5.10, and in Figure - 5.11 respectively.

PRESS & COLLATOR UTILIZATION (IN MINUTES)										CONT. & COST/COPY IN $S	
TITLES	PRESS 1			PRESS 2			COLLATOR			CONTRIBUTION IF SOLD	COST IF RETURNED
	BEG.	END	DUR	BEG.	END	DUR	BEG.	END	DUR		
HOUSEHOLD	0	95	95	—	—	—	96	189	93	1.99	0.36
TABOOS	—	—	—	0	156	156	189	279	90	5.55	0.55
CAPTURE	95	339	243	—	—	—	339	539	200	2.95	0.40
FASHION SHOW	—	—	—	156	381	225	539	674	135	4.02	0.33
WORLD EVENTS	339	596	257	—	—	—	674	914	240	2.62	0.43
DAY STREET	—	—	—	381	[illegible]	[illegible]	914	[illegible]	[illegible]	[illegible]	[illegible]
UNUSED TIME		404			152			271			
OVER USED TM		—			—			—			

REVENUE AFTER PRINTING	EXPECTED RETURNS COST	EXPECTED NET CONTRIBUTION
$ 2428400	$ 51715	$ 1959191

	DAY STREET	WORLD EVENTS	CAPTURE	FASHION SHOW	HOUSEHOLD	TABOOS
MEAN	210000	180000	150000	90000	70000	60000
SD	20000	15000	25000	30000	10000	45000
ACTUAL	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
RETURNS	15900	11925	19875	23850	7950	35775

Figure - 5.10: Screen 1 (Main Screen) of DSS 2

EXIT CHANGE TRIAL #

TRIAL #

7

HISTORICAL DATA

1 TO 7 ITERATIONS

CONTRIBUTION

CONTRIBUTION							
TABOOS	60000	60000	75000	75000	75000	100000	100000
FASHION SHOW	90000	115000	115000	115000	115000	115000	120000
CAPTURE	150000	150000	150000	150000	175000	175000	175000
[illegible]	210000	210000	210000	230000	230000	230000	[illegible]
WORLD EVENTS	180000	180000	180000	180000	195000	195000	195000
HOUSEHOLD	70000	70000	70000	70000	70000	70000	70000

QUNATITY

T	100000
F	120000
C	175000
B	[illegible]
W	195000
H	70000

Figure - 5.11: Screen 2 of DSS 2

5.3 - RESEARCH METHOD - THE EXPERIMENT

The two DSS were used to test the postulates listed in section 5.1. The procedure used in the experiment was as follows.

5.3.1 - THE TASK

The task involved in the experiment was to read the case and, with the help of a given model, to decide the number of copies of each title to print. Each subject was asked to use only the assigned computer model and to make decisions assuming the role of the circulation manager in the publishing firm. Each time a decision was made, the computer model presented the feasibility of that decision and its effect on the company's contribution. If the subject was not satisfied with the consequence of his/her decision, changes were allowed to be made and the process could be repeated until satisfactory results were obtained. The decision was then recorded on a form for the investigator's use. (A sample form is provided in the appendix). In order to measure the effectiveness of the DSS, it was necessary to set a time limit for subjects to provide their recommendations; a time limit of 30 minutes was given after they had learned to use the model.

5.3.2 - SUBJECTS

Subjects were recruited from the second year MBA program at the Western Business School. Participation in the experiment was voluntary, and a sample size of 100 was targeted (50 subjects in each group). Solicitation was done in the classrooms with the permission of the instructor. A brief overview of the experiment was given along with an information sheet (See Appendix - 8.5). Subjects who volunteered were asked to sign a consent form (A sample is provided in the Appendix - 8.6), and were paid $15.00 to cover their time and effort (about one and a half hour). In order to encourage their best efforts and to keep the experimental data from leaking to later participants, a $100.00 bonus was paid for the best performance in each group.

5.3.3 - EXPERIMENTAL DESIGN AND PROCEDURE

There were two groups; each used a different DSS. The subjects were randomly assigned to one of the test groups, where they were given the same case and were asked to perform exactly the same task. The experiment was conducted one subject at a time.

When a subject arrived, at a mutually convenient and arranged time, he/she was thanked for his/her participation, and informed again about the $15 payment to cover the cost of time and effort to participate in the experiment. He/she was also reminded about the $100 bonus award should he/she be the top performer in the group.

The experiment lasted up to one and one half hours to perform four separate sections of the task. At the start of the experiment, two information sheets were given: one listing the purpose and duration of each of the four sections with time limits, and the second providing the instructions on the experiment, and also explaining the operation of the computer model. (A sample of each is provided in the Appendix - 8.2 and Appendix - 8.3 respectively).

The first section of the experiment lasted thirty minutes where the subject read and analyzed the case. During this period, he/she was allowed to discuss with and ask questions of the investigator to ensure full understanding of the case involved. The use of a pencil, scratch paper, and a calculator was allowed to perform any necessary analysis.

The second section was a fifteen-minute tutorial on how to use the computer model. During this period, the subject learned how to start the computer model, the purpose of each menu, and the meaning of each display in the case context. These first two sections ensured adequate understanding of the case and familiarity with the model, in order for the subjects to perform the task efficiently.

In the third section, lasting thirty minutes, the subject started using the model to accomplish the task. During this period the subject was alone in performing the task. The investigator did not watch or interfere in the experiment, but was available for assistance when there was any question regarding the use of the model. The investigator neither answered any question concerning the subject's individual decisions nor interpreted the results. Five minutes before the end of this section, the subject was reminded of the time left, if the section had not already been completed.

In the fourth section of fifteen minutes, the subject was asked to record his/her decision and to submit all the material used during the experiment. All the documents collected were placed in the subject's file. This was to reduce the possibility of information concerning the task and decisions leaking out. At the end of this section, the subject was thanked and reminded again of the $100 bonus award, of which he/she would be notified in due time.

5.4 - RESEARCH HYPOTHESIS AND EXPERIMENTAL MEASURES

Based on the research objectives of this study given at the beginning of this chapter, the following hypotheses were developed.

Group 1 = Users of visual interactive decision support system (DSS 1)

Group 2 = Users of non-visual interactive decision support system (DSS 2)

5.4.1 - HYPOTHESES ON DECISION-MAKING EFFECTIVENESS AND CONSISTENCY

Hypothesis # 1.

Group 1 obtains higher contribution than group 2.

Hypothesis # 2.

Group 1 shows less variation in the contribution across subjects than group 2.

The variable used for examining these hypotheses (1-2) was contribution, which was a variable that subjects were asked to maximize. Therefore, if

$c_{i,k}$ = contribution recommended by the subject i in group k,

N_k = the number of subjects in group k

where $(i \in [1,N_k])$ and $(k \in [1,2]$ 1 = VI-DSS, 2 = non VI-DSS).

Average contribution for group k is

$$C_k = \frac{\sum_{i=1}^{N_k} c_{i,k}}{N_k}$$

with standard deviation = S_{Ck}

The two hypotheses can be written as:

H1: $C_1 > C_2$

H2: $S_{C1} < S_{C2}$

5.4.2 - HYPOTHESIS ON COMPREHENSION.

Hypothesis # 3

DSS 1 supports learning more effectively than DSS 2.

The learning model.

Learning, in the context of DSS, refers to the improved decision value obtained from repeated use of the DSS. Several studies have indicated that human performance improves with reinforcement or frequent repetitions [Yelle, 1979], [Sule, 1978].

Learning is time-dependent and externally controllable. There are several univariate and multivariate models that try to capture learning (see [Badiro, 1992] for a comprehensive survey). "Typical learning curves present the relationship between production cost and cumulative output based on the effect of learning" [Badiro, 1992]. In our case, the relationship is between the contribution and cumulative number of trials performed. The log-linear model given by Wright (1936) seems to be a simple, robust and appropriate model for measuring the learning imparted by DSS.

The log-linear model is based on the conventional learning curve that specifies the relationship between the contribution and cumulative number of trials. The conventional learning model is expressed as:

$$C^x = C^1 X^b$$

Where:

C^x = Contribution obtained in Xth trial

C^1 = Contribution in the first trial

X = Cumulative number of trials

b = The learning curve exponent

The above relationship indicates that the contribution will increase by a constant percentage as the cumulative number of trials double. If $b = 0$ there is no learning. If $b > 0$, it is assumed that the subject/group learns how to increase the contribution through additional trials. The parameter b is also referred to as the learning parameter [McClain, Thomas, Mazzola, 1992]

This learning curve on a log-log scale is a straight line, and the learning parameter, b, is the slope of the line. The log-linear equation is:

$$\log C^x = \log C^1 + b \log X$$

If DSS 1 communicates the displayed information to the user more effectively, then it is expected that subjects of group 1 would understand the system better. This improved understanding would result in the subjects in group 1 progressing faster towards a decision that yields a higher contribution. It is conjectured that learning would take place as shown in Figure - 5.12.

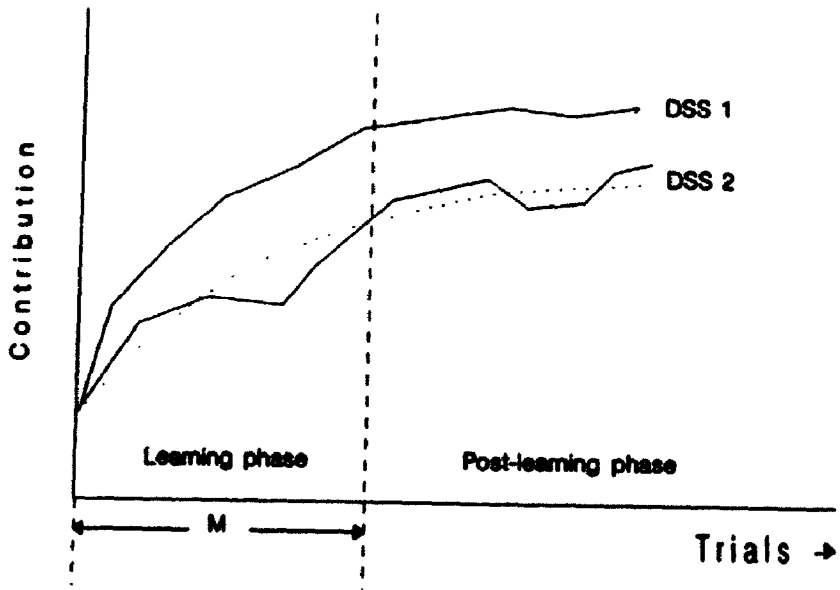


Figure - 5.12: Hypothesized view of the progress towards the solution.

At the beginning of the learning phase, the subjects iterate until they reach a proximity of the solution they later recommend, and at the end of the learning phase, they iterate to fine-tune the solution and balance the risk of magazine-returns across titles. Therefore, it seems that at the end of learning phase little or no change in the contribution is realized. If this conjecture is true, then the learning across subjects in group 1 will be higher than group 2.

In order to measure the magnitude of learning for each group, the learning parameter, b, can be estimated for each subject in the group by regression. Let:

$b_{i,k}$ = the learning parameter of subject i in group k, then B_k, the mean learning parameter for subjects in group k is

$$B_k = \frac{\sum_{i=1}^{N_k} b_{i,k}}{N_k}$$

The hypothesis can be written as:

H3: $B_1 > B_2$

Hypothesis # 4:

Subjects in group 1 "backtrack" less often than subjects in group 2.

BACKTRACKING

If the users of DSS 1 progress towards the recommended solution because they understand the system better, there is little incentive to try out less effective, or trial and error, decisions. Therefore, it is expected that their progress will generally show a systematic increase in the contribution from one trial to the next. Examining random decisions may result in backtracking, i.e., decisions which lead to a reduction in contribution.

It is however true that sometimes trial and error decisions help in reaching the proximity of the global maximum quickly. Systematic progress may lead the model user to a local maximum (if any) rather than the global maximum, and thus may hinder further improvement in the solution obtained. The DSS for this study were tested and were found to have no local maxima.

When a DSS imparts "learning" then it is reasonable to expect systematic learning and at the end some trials of very different solutions to ascertain global optimality. The trials at the end may also result in backtracking. This hypothesized view is shown in Figure - 5.13.

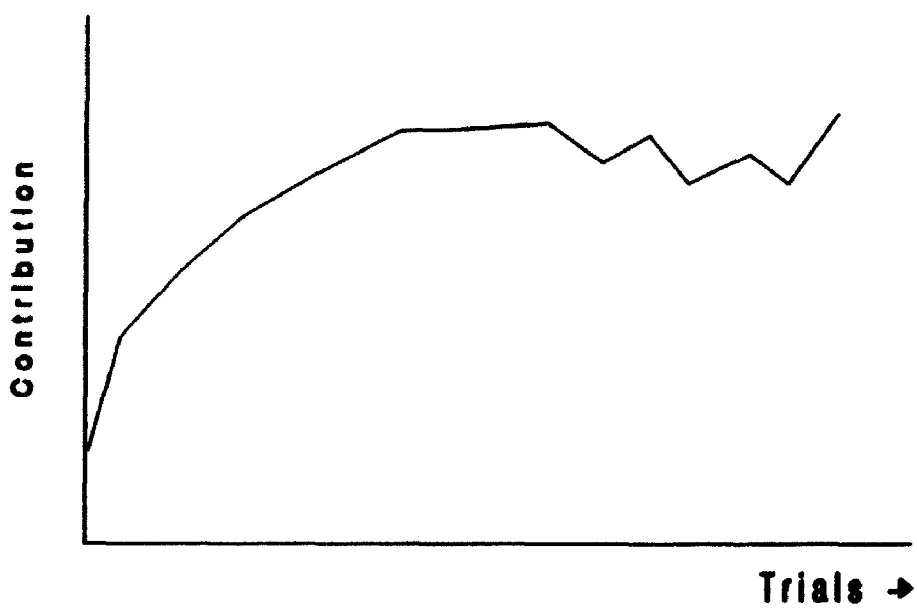


Figure - 5.13: Hypothesized view of backtracking.

The number of backtracks resulting from ascertaining global optimality is expected to be less than the number of backtracks resulting from a DSS that imparts little or no learning. The difference in the number of backtracks should, therefore, reflect learning and comprehension difference between the two groups.

The number of backtracks in a given session is shown by the number of sign changes in the marginal contribution between consecutive trials. Therefore, let:

$f_{i,k}$ = number of sign changes during the session by subject i in group k, and

$m_{i,k}$ = number of trials performed by subject i in group k,

then F_k, the mean percentage sign changes during the session for subjects in group k, $(k \in [1,2])$ is:

$$F_k = \frac{\sum_{i=1}^{N_k} (f_{i,k}/m_{i,k})*100}{N_k}$$

Then the hypothesis can be expressed as:

H4: $F_1 < F_2$

5.4.3 - HYPOTHESES ON DECISION EXTREMITY AND CONSISTENCY.

Hypothesis # 5.

Users of DSS 1 examine fewer extreme decisions than users of DSS 2.

The task of subject i in the experiment was to make decisions concerning the number of copies to print for each of the six titles, that is $p_{1,i}$ to $p_{6,i}$. An extreme decision was defined as the quantity of a title recommended for printing that has less than a 2.5% probability of selling out. (A demand observation above this level would be considered a statistical outlier, i.e.

probability $(p_{t,i} \geq (\mu_t + 1.96\sigma_t)) < 0.025$

where $p_{t,i}$ = number of copies of title t recommended for printing by subject i

μ_t = mean demand of title t, with

σ_t = standard deviation of the distribution $(t \in [1,6])$, $(i \in [1,N_k])$)

In hypothesis 4, it was expected that group 2 would make more trial and error decisions than group 1. The trial and error decisions may contain some extreme decisions. Therefore it is expected that the number of extreme decisions examined by group 1 would be less than group 2.

Let:

$e_{i,k}$ = the number of extreme decisions examined by subject i in group k,

$m_{i,k}$ = number of trials performed by subject i in group k,

Then E_k, the mean number of extreme decisions per trial examined by each group is:

$$E_k = \frac{\sum_{i=1}^{N_k} e_{i,k}/m_{i,k})}{N_k} \qquad \ldots (k \in [1,2]), (i \in [1,N_k])$$

The hypothesis can be expressed as

H5: $E_1 < E_2$

<u>**Hypothesis # 6t, ($t \in [1,6]$)**</u>

Group 1 shows less variation in their decisions across subjects (for each title) than group 2.

In the previous hypothesis, it was conjectured that group 1 would avoid trial and error decisions due to improved understanding of the system. The decision made by the subjects in group 1, therefore, should be clustered around a mean, and should show less variation across subjects when compared with group 2. Further, if hypothesis 5 had too strict a definition for an extreme decision, then it was expected to be reflected in this hypothesis.

Let:

$x_{t,i,k}$ = the number of copies of title t recommended by subject i, in group k

$\{(t \in [1,6]), (i \in [1,N_k]), (k \in [1,2])\}$

the group average number is

$$X_{t,k} = \frac{\sum_{i=1}^{N_k} x_{t,i,k}}{N_k} \quad \text{........ for each t } (t \in [1,6])$$

with standard deviation $S_{X,t,k}$.

Then the hypothesis can be expressed as

H6t. $S_{X,t,1} < S_{X,t,2}$ ... for each t $(t \in [1,6])$

5.4.4 - HYPOTHESES ON DSS EFFICIENCY

Hypothesis # 7

Group 1 takes less time than group 2 to provide the recommended solution.

if $t_{i,k}$ = the time (clock time in minutes) taken by subject i of group k to provide the recommendation. then the mean time for each group is :

$$T_k = \frac{\sum_{i=1}^{N_k} t_{i,k}}{N_k} \qquad (i \in [1, N_k]), (k \in [1,2])$$

Then the hypothesis can be expressed as:

H7: $T_1 < T_2$

Hypothesis # 8

Group 1 makes fewer trials than group 2 to reach the recommended solution.

if $m_{i,k}$ = the number of trials made by subject i of group k, $(i \in [1,N_k])$,

$(k \in [1,2])$

then M_k, the group average number of trials is

$$M_k = \frac{\sum_{i=1}^{N_k} m_{i,k}}{N_k}$$

Then the hypothesis can be expressed as:

H8: $M_1 < M_2$

5.6 - SUMMARY OF HYPOTHESES

HYPOTHESES	DESCRIPTION	MEASUREMENT
HYPOTHESES ON DECISION-MAKING EFFECTIVENESS AND CONSISTENCY		
H1	Group 1 obtains higher contribution than group 2.	$C_1 > C_2$
H2	Group 1 shows less variation than group 2.	$S_{C1} < S_{C2}$
HYPOTHESES ON COMPREHENSION		
H3	DSS 1 supports learning more effectively than DSS 2.	$B_1 > B_2$
H4	Group 1 "backtracks" less often than group 2.	$F_1 < F_2$
HYPOTHESES ON DECISION EXTREMITY AND CONSISTENCY		
H5	Group 1 examines fewer extreme decisions than group 2.	$E_1 < E_2$
$H6_t$	Group 1 shows less variation in the decisions across subjects (for each title) than group 2.	$S_{X,t,1} < S_{X,t,2}$ ($t \in [1,6]$)
HYPOTHESES ON EFFICIENCY		
H7	Group 1 takes less time than group 2 to provide the recommended solution.	$T_1 < T_2$
H8	Group 1 makes fewer trials than group 2 to reach the recommended solution.	$M_1 < M_2$

Table - 5.1: Summary of hypotheses and their measurements

6.0 - DATA COLLECTION, ANALYSIS AND DISCUSSION OF RESULTS

6.1 - DATA COLLECTION

The experiment began during mid-November and lasted until 24 December 1992. Eighty second year MBA students at the Western Business School participated in the experiment.

For the experiment, the volunteer subjects were randomly assigned to one of the two groups and were allowed to perform the experiment one at a time. The experimental data was collected in two modes. The recommended print-quantity of magazines and its corresponding net-contribution was recorded on a data-form (see Appendix - 8.4) by the subject and submitted at the end of the experiment. The data concerning their progress from first trial to the last trial was recorded by the computer automatically and was saved as a computer file at the end of the computer session. One subject from group 1 tried to do something during the computer session that was uncalled for and, in the process, jammed the computer keyboard. As a result the subject's computer file was destroyed. Therefore the contribution data submitted by this subject was also excluded from the analysis.

Another subject, but from group 2, had submitted the recommendation for the print-quantity which was below the demand-mean value (starting value for all subjects). On questioning him he said "I tried to reduce the magazine returns". It is not known why he was so conservative when his recommendations reduced the net-contribution considerably. Analysis with this subject's data included gave a higher difference between the two groups. In order to be conservative this subject's data was excluded as well.

6.2 - DATA ANALYSIS

For the data analysis, seventy-eight (39 in each group) ASCII files of interaction data created by the DSS, were analyzed to extract required information such as number of trials performed, number of extreme values used and number of backtracks made during the computer session. The extracted data was then transferred to a separate file. A further analysis was performed on each of the ASCII files to create new files for estimating the learning exponent by regression analysis. The analysis was performed using a FORTRAN program, which helped save time and avoid manual errors. The extracted information including the estimated values of the learning exponent was then transferred to a LOTUS spreadsheet for further analysis. The print-quantity data and the contribution data from the data-form submitted by the subjects were also transferred to a LOTUS spreadsheet. The two spreadsheets were then used with SAM (Statistical Applications Macros) [Bell, and Newson, 1989] for hypothesis testing using the hypotheses formulated in section 5.4. In conducting the hypothesis test separate sample variances were used. The results were as follows:

6.2.1 - HYPOTHESES ON DECISION-MAKING EFFECTIVENESS AND CONSISTENCY

Group 1 (using VI-DSS) obtained a significantly higher contribution, C_1, than group 2 (using non VI-DSS); (Table 6.1) and group 1 showed less variation across subjects. The analysis suggests that DSS 1 (VI-DSS) helped subjects obtain more effective and consistent decisions as hypothesized (H1 and H2). Both hypotheses were supported by the data at 0.05 level of significance.

HYPOTHESES ON DECISION-MAKING EFFECTIVENESS AND CONSISTENCY			
H1: Group 1 obtains higher contribution than group 2			
VARIABLE MEASURED: $C_1 > C_2$			
RESULTS			
C_1	**C_2**	**P-value**	**Significance at 0.05**
2266514	2237690	0.04	Significant
H2: Group 1 shows less variation than group 2.			
VARIABLE MEASURED: $S_{C1} < S_{C2}$			
RESULTS			
S_{C1}	**S_{C2}**	**P-value**	**Significance at 0.05**
36589.32	55931.57	0.000	Significant

Table - 6.1: Results of hypotheses on decision making and consistency

6.2.2 - HYPOTHESES ON COMPREHENSION

The second set of hypotheses concerns the comprehension or learning imparted by the DSS-displays to the subjects. The first hypothesis measured the learning parameter for each group. If the learning parameter, b, is interpreted as given in section 5.4.2 then VI-DSS can be said to have had provided significantly higher learning at the 0.1 level but not at 0.05. The second hypothesis measured the number of backtracks committed while using the given DSS. The data significantly supported this hypothesis as well. The Table - 6.2 shows the test values.

HYPOTHESES ON COMPREHENSION			
H3: DSS 1 supports learning more effectively than DSS 2.			
VARIABLE MEASURED: $B_1 > B_2$			
RESULTS			
B_1	B_2	P-value	Significance at 0.1 but not at 0.05
0.07056	0.023844	0.067	Significant
H4: Group 1 backtracks less often than group 2			
VARIABLE MEASURED: $F_1 < F_2$			
RESULTS			
F_1	F_2	P-value	Significance at 0.05
27.47%	34.20%	0.000	Significant

Table - 6.2: Results of hypotheses on comprehension

6.2.3 - HYPOTHESES ON DECISION EXTREMITY AND CONSISTENCY

Table - 6.3 shows the results of testing the hypotheses on decision extremity and consistency. Group 1 examined fewer extreme decisions than group 2. The results indicate that the data supports the hypothesis significantly at 0.05 level. The decisions made by group 1 about print-quantities were also found to be consistent across subjects and show significantly less variation than group 2. The data supported the hypothesis for five of the six magazines at the 0.05 level and the sixth at 0.1 level (but not 0.05).

HYPOTHESES ON DECISION EXTREMITY AND CONSISTENCY				
H5: Group 1 examines a lower number of extreme decisions than group 2.				
VARIABLE MEASURED: $E_1 < E_2$				
RESULTS				
	E_1	E_2	P-value	Significance at 0.05
	0.9598	1.1517	0.002	significant
$H5_t$: Group 1 shows less variation in the decisions across subjects (for each title) than group 2.				
VARIABLE MEASURED: $S_{x,t,1} < S_{x,t,2}$ $(t \in [1,6])$				
RESULTS				
t	$S_{x,t,1}$	$S_{x,t,1}$	P-value	Significance at 0.05
1	12200.31	17226.65	0.020	Significant
2	11378.26	23070.96	0.000	Significant
3	12611.90	24493.77	0.000	Significant
4	13346.21	19314.67	0.005	Significant
5	17557.65	21430.23	0.095	Not significant but significant at 0.1
6	23708.95	37848.82	0.002	Significant

Table - 6.3: Results of hypotheses on decision extremity and consistency

6.2.4 - HYPOTHESES ON EFFICIENCY

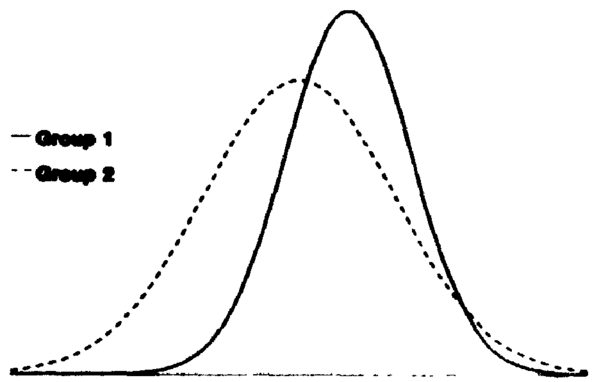
The fourth set of hypotheses concerns efficiency of the two DSS. There were two hypotheses that were postulated, one concerning the number of trials performed and the other the total time utilized to provide the recommendations. Group 1 performed an insignificantly lower number of trials than group 2, and as far as the time was concerned none of the subject in either group showed any variation.

HYPOTHESES ON EFFICIENCY			
H7: Group 1 takes less time than group 2 to provide the recommended solution.			
VARIABLE MEASURED: $T_1 < T_2$			
RESULTS			
T_1	T_2	P-value	Significance at 0.05
30	30	---	---
H8: Group 1 makes fewer trials than group 2 to reach the recommended solution.			
VARIABLE MEASURED: $M_1 < M_2$			
RESULTS			
M_1	M_2	P-value	Significance at 0.05
27.68	28.18	-0.428	Not significant

Table - 6.4: Results of hypotheses on efficiency

6.3 - DISCUSSION OF RESULTS

It is apparent from the analysis of the experimental data that the visual interactive DSS was more effective than the non VI-DSS in many respects. All hypotheses except those concerning efficiency were supported by the data. Group 1 obtained a higher contribution on average than group 2, and also had a tighter distribution. Figure - 6.1 shows the difference between the two groups in decision-making effectiveness and consistency in the form of probability distributions[4].



CONTRIBUTION		
GROUPS	MEAN	STD. DEVIATION
Group 1	2266514	36589.32
Group 2	2237690	55931.57

Figure - 6.1 : Comparison of the contribution between the groups.

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4 -> Normal curves are used here and in later figures only to illustrate graphically the difference between the two groups. No claim is being made that the empirical distributions are normal.

The initial contribution with which all subjects had started the experiment was $1,959,000 and the highest or optimal value obtainable was 2,315,390.[5] Both groups were able to obtain a maximum contribution which was about 98% of the optimal amount, and the minimum and mean contributions were higher for group 1 than for group 2 as shown in Table 6.5.

GROUP	INITIAL Contribution	CONTRIBUTION OBTAINED						OPTIMUM
		MIN	%	MEAN	%	MAX	%	
1	1959000	2160621	56.57[6]	2266514	86.28	2309214	98.26	2315390
2		2082077	34.53	2237690	78.19	2310589	98.65	

Table - 6.5: Comparison of the contribution between the groups.

The results on contribution should be no surprise given the results of the second set of hypotheses. The second set of hypotheses suggested that visual displays of VI-DSS provided a better comprehension of the problem situation and the DSS; as a result, the decision makers performed more effectively. The learning parameter for the groups suggested that VI-DSS provided about 4% higher learning (which translates to 4% higher net contribution) each time the number of trials double. The learning curve for each group is shown in Figure - 6.2 and the distribution of the learning parameter for the two groups is shown in Figure 6.3

5->: Prior to the experiment both DSS had been tested for a sufficiently long time and the contribution obtained was expected to be the optimal or near optimal.

6->: (2160621 - 1959000)/(2315390-1959000) = 56.57 %

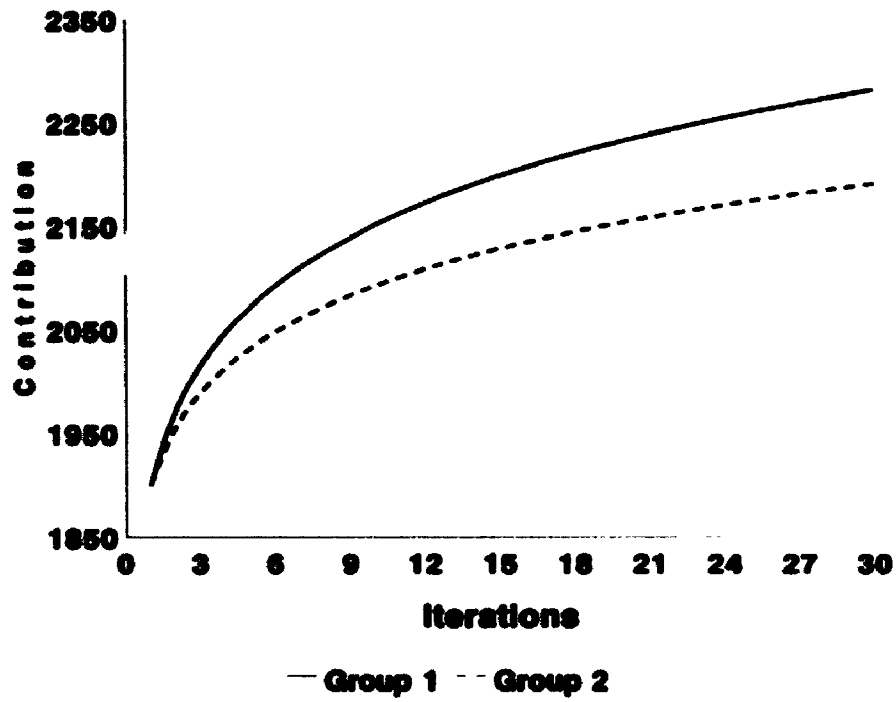


Figure - 6.2 (a): Learning curves for the two groups

Figure 6.2 (a) comp^^es the fitted learning curves for the two groups where both groups started from the same initial conditions and where the increase in contribution is based only on the experience and insight gained by subjects during the previous trials. The curves indicate learning imparted by the DSS. As the figure shows, DSS 2 (the DSS used by group 2) provides little learning compared to DSS 1. As a result, it seems group 2 subjects tried some trial-and-error decisions including some extreme decisions -- as supported by hypotheses 4,5 and 6. It is possible for group 2 therefore to take an early lead over group 1 and thereafter making little progress in increasing the contribution. This possible scenario is shown in figure 6.2 (b).

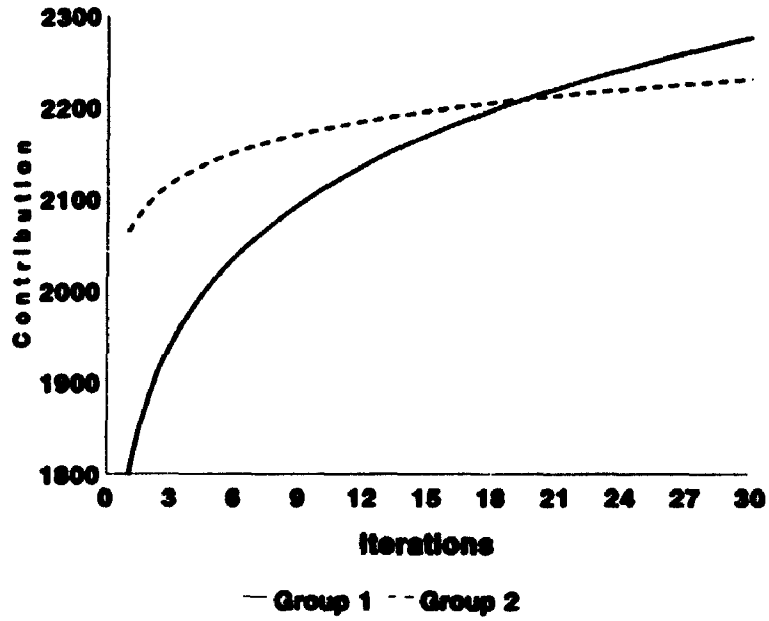
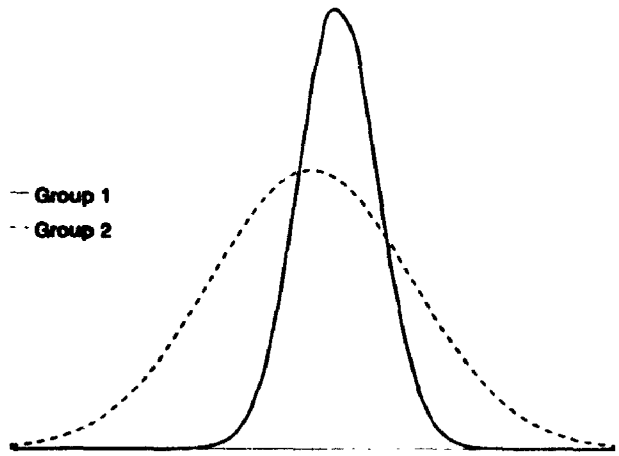


Figure - 6.2 (b): The learning curves for the two groups with trial of trial-and-error decisions.

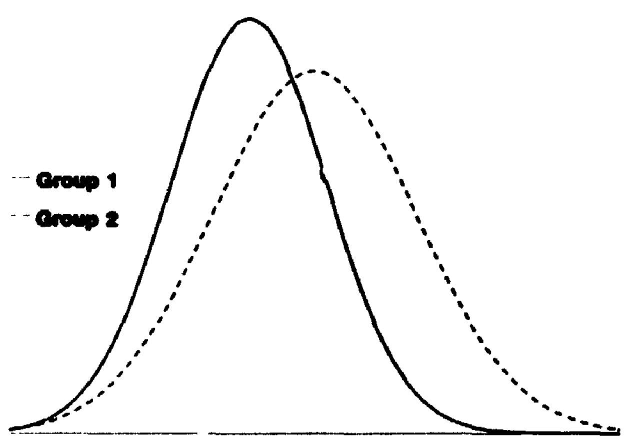


LEARNING PARAMETER (b)		
GROUPS	MEAN	STD. DEVIATION
Group 1	0.070562	0.070559
Group 2	0.023844	0.176606

COEFFICIENT OF DETERMINATION (R^2)		
GROUPS	MINIMUM	MAXIMUM
Group 1	1%	92%
Group 2	1%	55%

Figure - 6.3: Comparison of Learning effects of the two DSS (Groups)

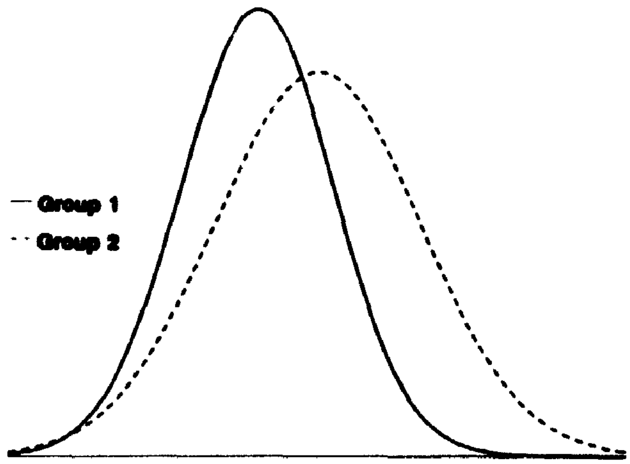
The second hypothesis on comprehension, measured in terms of the number of backtracks committed, reinforces the higher learning imparted by the VI-DSS. Since decision makers using VI-DSS had a better comprehension of the system, they progressed systematically with less backtracking. On the other hand, decision makers using non VI-DSS did not exhibit much learning; as a consequence, they tried many random decision which sometimes yielded a high contribution and sometimes a low contribution. Lack of comprehension among group 2 subjects was evident from the slope of their individual learning lines (regression lines). A majority of the subjects in group 2 had either negative values or had close to zero value for the slope. Similarly a majority of the subjects in group 2 had single digit values for the coefficient of determination, R^2, while a majority of subjects in group 1 had double digit values. The data suggested that VI-DSS provided a significantly higher comprehension than the second DSS. The Figure - 6.4 shows the distribution of the number of backtracks in each group.



NUMBER OF BACKTRACKS		
GROUPS	MEAN	STD. DEVIATION
Group 1	27.47%	7.97%
Group 2	34.20%	10.44%

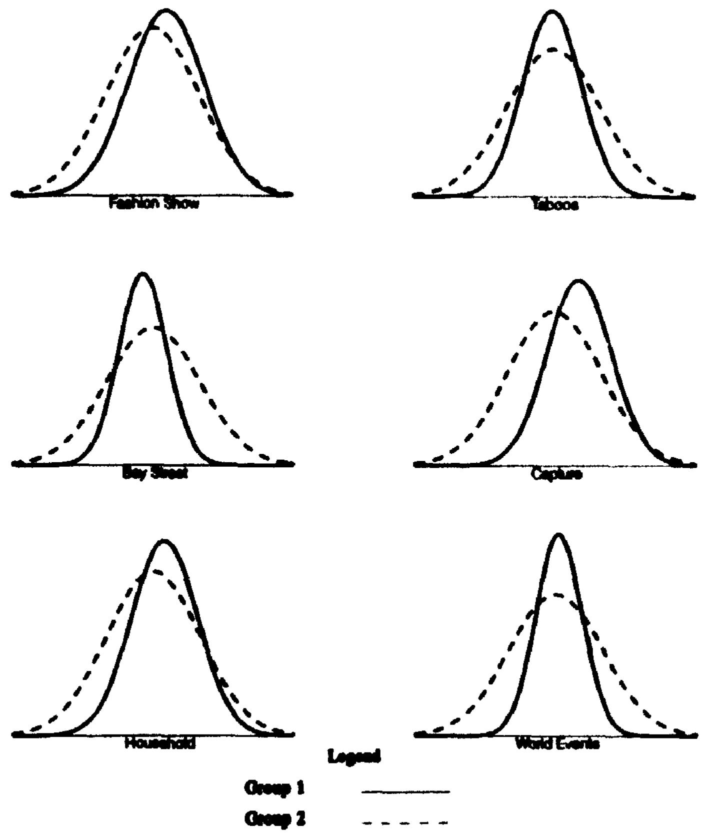
Figure - 6.4: Comparison of the number of Backtracks between the two groups

The third set of hypotheses on decision extremity and consistency were also supported by the data. Before the commencement of the experiment there was a concern that the first hypothesis might be too severe. An extreme decision was defined as the quantity of a title recommended for printing that had less than 2.5% probability of selling out. It was hoped that should this test be too severe then the second hypothesis (on decision-variation across subjects) would capture the essence of the first one. As it turned out there was no need for concern. Despite the severity the data supported the hypothesis significantly. The hypothesis on decision variation across subjects were also significant. This set of hypotheses further strengthened the learning concept of the VI-DSS. The Figure - 6.5 and Figure - 6.6 show the comparative distributions for each group on decision extremity and decision consistency.



NUMBER OF EXTREME DECISIONS		
GROUPS	MEAN	STD. DEVIATION
Group 1	0.9598	0.6959
Group 2	1.5173	0.9435

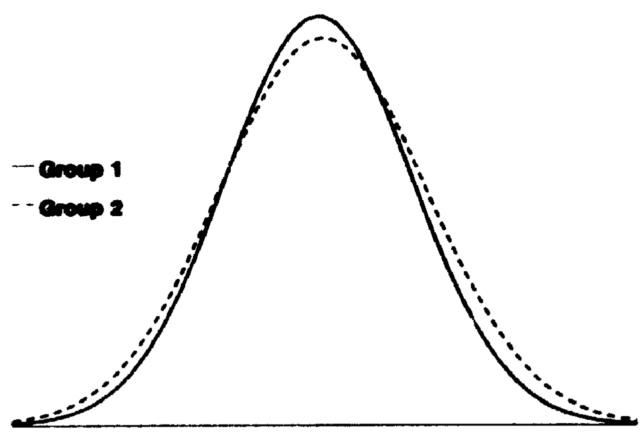
Figure - 6.5: Comparison of the number of Extreme decisions between the two groups



PRINT-QUANTITY OF THE MAGAZINES						
GROUPS	FASHION SHOW		TABOOS		BAY STREET	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Group 1	131595	17557	115255	23708	242230	12611
Group 2	125256	21430	116407	37848	247628	24493
GROUPS	CAPTURE		HOUSEHOLD		WORLD EVENTS	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Group 1	181544	13346	79643	12200	195090	11378
Group 2	171314	19314	75562	17226	193421	23070

Figure - 6.6: Comparison of the print-quantity of each magazine between the two groups

The last set of hypotheses was designed to measure DSS efficiency, i.e., the number of trials performed while using the DSS and the total time taken to provide the final recommendations. The efficiency of the VI-DSS was not as expected. The data shows that the number of trials performed by group 1, using VI-DSS, was marginally less than the group 2: the difference was not statistically significant. The figure 6.7 shows the distribution of the number of trials performed for each group.



GROUPS	MEAN	STD. DEVIATION
Group 1	27.68	11.08
Group 2	28.18	12.35

Figure - 6.7: Comparison of the number of trials between the two groups

The reason for not obtaining the results as hypothesized appeared to result not from the inefficiency of the VI-DSS but rather from inadequacy of data measurement. The time limit of 30 minutes allowed to use the DSS was insufficient to satisfy the subject's curiosity about the DSS capabilities, (or to solve the problem). Every subject used the full 30 minutes of allotted time. Even though the final recommendation given by a majority of subjects did not come from the last trial, the subjects appeared to want to continue working with the DSS. On asking them about adequacy of time, a typical response was that "it is a different kind of model from what I am used to; I could play with it for hours" or "I got the hang of the model during the last few minutes". It seems that subjects tried to test other possible combinations of the six decisions they were expected to make. Since there were a very large number of possible decision combinations that kind of curiosity could not be satisfied, no matter what the time allowed. Yet some subjects tried to satisfy their curiosity by changing model parameters that were not anticipated; as a consequence they had to ask for assistance to continue their session. Both DSS were designed to take such "abuse", but one subject managed to lock the key-board and destroyed his data file.

Before the experiment began, the time limit of 30 minutes was examined carefully. A pilot test with the DSS had suggested that providing more than 30 minutes might allow all users to reach the proximity of the optimal solution, thus might not yield any significant difference between the two DSS. In hind-sight it seems that it was not a good strategy to try to measure both effectiveness and efficiency with these DSS.

7.0 - LIMITATIONS AND RESEARCH IMPLICATIONS

The data obtained through the experiment generally support the hypotheses proposed. If generalizable, the implications of the results are quite profound, but the generalization issue is a difficult one.

7.1 - LIMITATIONS

Generalizability of the results of this study is restricted due to several limitations inherent in the study.

1. SUBJECT SENSITIVITY: The experiment in the study used MBA students as surrogates for practising managers. MBA students represent managers well because many have had managerial experience, and all have been exposed to more than a year of Western's MBA program. The fact that they are not in a true managerial situation or under the same time-pressure to make decisions may, however, bias the results.

2. TASK SENSITIVITY: The study assumed that the techniques used in the DSS are equally good for the selection, allocation and scheduling tasks involved in the case. Additional techniques or information, such as dual variables, could have

been provided to the subjects to aid in the tasks, but it was felt that for the given case situation additional techniques/information would complicate the task. The techniques used may be suitable for a publishing business environment, but may not be generalizable to other business situations or to decision making in general.

3. RESOURCE LIMITATIONS: Because of resource limitations, the experiment lasted seven weeks. Consequently there was a danger of information being leaked from early participants to later participants. A performance comparison between early and later participants did not suggest information leakage. Introduction of the "bonus" award to the best performer in each group attempted to minimize the danger but might not have eliminated it.

4. MODEL SENSITIVITY: It was assumed that both DSS provided to the subjects in the experiment were equally "good". As far as possible, an attempt was made to provide most appropriate and logical DSS. A bad non-VI-DSS may be worse than a good VI-DSS, even though the former DSS might be better than the later one when both were equally "good" or equally "bad". The effort to build both DSS from a single software "package", to make both DSS the same in terms of program logic and model interactions, and to have equivalent output displays aimed to minimize the effect of model sensitivity.

7.2 - RESEARCH IMPLICATIONS

Despite limitations the two DSS yielded results generally as hypothesized (Compare Figure - 5.11 and Figure - 6.2 (a)) with implications for decision-making, LP, and VIM.

The implications for managerial decision-making are that VI-DSS may support selection, allocation, and scheduling tasks demonstratably better than non-VI-DSS. The results lend some support to Vessey's "Cognitive Fit" theory [Vessey, 1991], according to which decision making performance is best achieved when there is a match between task, process and information emphasized in the displays. Decision making in this study involved repetitive selection, allocation, and scheduling tasks to improve upon the previous solution, until a satisfactory one was obtained (or until the time-limit was reached). According to Vessey's "Cognitive Fit" theory, allocation and scheduling tasks are classified as spatial tasks which are said to be performed better with graphics; while allocation tasks are analytical tasks which are said to be performed better with tables.

Although the experiment conducted in this study did not isolate the individual tasks involved in the decision making, more of the tasks matched those said to be supported by graphical displays rather than tabular displays. The group provided with the VI-DSS made more effective decisions than the group provided with the non-VI-DSS, providing support for Vessey's theory.

Vessey quotes the work done by Simon and Hayes (1976) to suggest

> "that subjects construct different mental representations for structurally similar problems (isomorphs); that is, they derive the mental representation that is most readily available from the problem representation. They then select problem-solving processes that are compatible with their mental representations" [Simon and Hayes, 1976] (tense changed).

Vessey further reasoned from Simon and Hayes' work that decision makers use similar processes for a given task and problem representation. This implication can also be drawn from the results of this thesis. The learning curves (Figure 6.2) show that group 1 learnt more than group 2 in every trial, and that group 1 progressed from a lower level of contribution than group 2. This is explained by the difference in the process used by the subjects. Group 1 appeared to have made incremental changes in a few decision variable at a time, while group 2 appeared to have made random changes in many, if not in all six, decision variables at a time. This process coulc explain the results obtained in this thesis, but explicit testing must be conducted to relate this to Vessey's reasoning.

This thesis suggests that when problem representation is graphic and highly interactive ("dynamic") then what a subject learns from the changing displays has an effect on the decision made. This thesis also suggests that learning is display dependent. The learning therefore, may complement the decision maker in the process of matching the task involved in the decision with the given problem representation (display). Then, what process do decision makers use to learn from a given display? This question needs to be investigated explicitly.

This study suggest that LP is interpretable and usable without mastering the mathematics of LP. The use of visual displays and iconic graphics in particular, appear to be useful in formulating the input for LP, and also in communicating the output to the user. The users would improve their performance should LP-software developers add graphical front and back ends by exploiting the existing computer technology.

The results of this thesis suggest that VIM helps in building effective DSS. The methodology used to construct the DSS was simple, easy to adopt and fast to build. The resulting model was effective: users could reach a solution that was 95% of optimal in 30 minutes.

The VIM software package, used to build the DSS, was not difficult to use, and was very flexible and allowed user desired displays to be built without complications. The package is particularly useful when MS-OR techniques like LP need to be used inconspicuously.

This thesis was the first attempt to develop a LP based VI model and use it to solve a managerial problem. The thesis also provided the first empirical test of an LP based VI model. The results suggest that LP based VIM are useful in solving managerial problems, and by extension, VIM using other type of algorithm may also be useful problem solving tool. Previously, there was theoretical and experiential support for the usefulness of a VIM, the results of this study adds experimental support as well.

APPENDICES

8.1 -MK PUBLISHING INC.

It was a Wednesday morning in October 1991. Before noon Howard Adams, VP Circulation, MK Publishing Inc., had to decide how many copies of each of 6 magazines to print in order to best utilize the available press shop capacity, and provide maximum contribution to the company.

8.1.1 - THE COMPANY

MK Inc. was a large conglomerate of many companies in the communication field. MK dealt in publishing, broadcasting, newspapers, business forms, and commercial printing. The MK subsidiaries operated independently, but accommodated each other where complementary services existed. MK Publishing Inc., the publishing subsidiary, published half a dozen weekly and monthly magazines (see table 1), and that were printed at MK Printing, the printing subsidiary (popularly called the press shop). The press shop was a commercial printing press, where 30 % of the business came from MK Publishing, and the rest from other companies. The press shop preferred having long-term contracts with the publishers; that way they could estimate their excess capacity. The excess capacity was filled by short or one-time contracts to print catalogues, brochures, calendars, books, and flyers.

8.1.2 - PUBLISHING, PRINTING AND CIRCULATION PROCESS

Publication of a magazine involved collection of advertisements, setting, layout, art work, and preparation of manuscripts. Because the art work for the advertisements took many days to prepare, the publishers sold the advertisements weeks before the actual publication. Since the manuscripts contained descriptions and analyses of the latest events, they were not prepared until the last moment. While reviewing the final document, the publishers, with the assistance of the circulation department, decided on the number of reproductions that were required. Usually it was the same quantity every week, but sometimes a change was made to reflect other parameters such as sensitivity to the magazine content and prior advertisements. Then the copy was delivered to the press shop.

The press shop prepared a film of the manuscripts, and then a printing plate from the film. The production director assigned the magazine to a printing press, based on the total quantity to be printed. The plate was then mounted on the assigned press to take trial runs. It generally took one to two-and-a-half hours for the setup and trial runs.

Therefore, a title was printed on only one press. After obtaining the satisfactory printing quality, the actual printing commenced. The press shop used two presses for the six titles. The presses could print any title with as many as 32 pages in a single impression, but the printing speed varied with the number of pages and the color combinations in a title. (Table 2)

The printed pages were then transferred to the finishing area, where pages were collated, stitched (stapled), cut, and trimmed. The collator in the press shop was of very high capacity. It could organize all titles in almost a single set up; however, the speed at which it organized depended on the number of printed sheets[7] and the press where the title was printed. (Table 2)

The finished titles were then taken to a distribution center. The distribution occurred each Friday morning; first, they were sent to out-of-town subscribers by mail, and then to the agents for newsstand distribution.

Any copy unsold by the newsstand was returned. The agents collected and trucked them back to the publisher. The publisher counted and shredded the copies before sending them for recycling. The cost of processing the returns was 10 cents per copy returned (excluding the cost of paper, ink, and printing that had already gone into it).

8.1.3 - THE COST STRUCTURE

Most consumer magazines in Canada depended on advertisements to subsidize the cost of publishing a magazine. The cost of printing and distribution was often more than the subscription price. Therefore, the publishers squeezed printers for the lowest possible price. Money saved in printing would usually go toward the profitability.

The publishers usually had long-term contracts for printing their magazines. The contract price depended on the number of pages, colors, inserts, and the quality of paper used. The newsstand price and contribution per title are given in Table 3.

For the press shop, the cost of material (essentially for paper and ink) was about 50% of the contract price. The cost of running a press and the collator is given in table 2. This cost includes 30% of direct labor. Since the press time was reserved in advance, overtime was almost non-existent. If the printing or collating time exceeded the reserved time, then the cost of printing would be prohibitively expensive.

[7] -> The printed sheets could be 4, 8, 16, or 32 magazine pages.

8.1.4 - THE PROBLEM

Howard Adams had gone to the distribution center, where he was concerned to see piles of magazines stacked in the corridor. These were the copies of MK publications that had not been sold at the newsstand the previous week, and had been returned for destruction. During that week the returns were about 25% for 2 titles and about 5% for the others.

8.1.5 - THE TASK

After the visit to the distribution center, he suspected that MK was not printing the right mix. For two titles they printed far more than they sold, and the other four were inadequate to realize potential sales. He looked at the actual sales during last two years, and observed no particular trend that he had missed. He used the past few years' data and estimated their distribution (Table 1).

He realized that profitability was very sensitive to the sales, especially newsstand sales. Any magazine that remained unsold was a foregone profit. He thought to himself that if they reduced the quantity, they would not have enough to display on the newsstand. For adequate exposure at least one copy of each magazine should remain on each newsstand at the end of the sale period; otherwise a stockout could result in lost sales.

Further, the reduction in the number of copies would result in reduced revenue for the press shop. The press was part of the organization, and had recently moved to a new location with modern equipment. They needed all the revenue they could get to recover their investment. He wondered if a reduction in the copies printed would make a substantial change in the organization's bottom line.

He was aware that the press shop was using a computer model that had the printing cost and revenue data built into it. After the circulation department had indicated the quantity to print, the model was used for title-to-press assignment, and for estimating total press shop profit. He wondered if he should use that model to decide the quantity and assign the titles-to-presses simultaneously. That way he could determine the quantity that would give the best contribution per magazine, and at the same time utilize the press shop capacity optimally. It was better to maximize the whole organization's profitability, instead of maximizing the profitability of the publishing and printing subsidiaries separately.

Assignment: If you were in Howard Adam's shoes, how many copies of each title would you print ? To answer the question, please use the accompanying model that has all the printing costs built into it (i.e. all the data shown in Exhibit 1).

8.1.6 -EXHIBIT 1

(DATA BUILT INTO THE MODEL)

Table 1

WEEKLY SALES IN THOUSANDS

MAGAZINE	TITLE	MEAN	STANDARD DEVIATION
1	**Bay Street**	210	20
2	**World Events**	180	15
3	**Capture**	150	25
4	**Fashion Show**	90	30
5	**Household**	70	10
6	**Taboos**	60	45

Table 2

PRESS SHOP DATA

	Printing								Finishing		
	Printing rate per hour BS	WE	CA	FS	HH	TB	Hours Avail.	Cost/ hour	Collator rate/hr.	Hours Avail.	Cost/ hour
Press 1	39**	42	37	34	44	33	16.25	$ 1920	45**	25	$ 800
press 2	27	30	26	24	31	23	16.25	$ 1680	40		

** -> Thousands of magazines per hour

Table 3

PRICE AND CONTRIBUTION

	Magazines BS	WE	CA	FS	HH	TB
Cover price	$ 4.00	3.00	3.25	4.25	2.25	6.00
Paper & ink	0.38	0.38	0.30	0.23	0.26	0.45
Contribution	**$ 3.62**	**2.62**	**2.95**	**4.02**	**1.99**	**5.55**

(Before press, collation, and return processing cost)

8.1.7 -EXHIBIT 2

(DATA NOT BUILT INTO THE MODEL)

Table 4

SALES DATA FOR MOST RECENT ISSUE

	Magazines					
	BS	WE	CA	FS	HH	TB
COVER PRICE	$ 4.00	3.00	3.25	4.25	2.25	6.00
QTY PRINTED	250,000	210,000	175,000	100,000	75,000	80,000
RETURNS	41,000	30,810	31,750	28,100	10,200	44,650
Cost of returns per copy						
Paper & ink	0.38	0.38	0.30	0.23	0.26	0.45
processing	0.10	0.10	0.10	0.10	0.10	0.10
	0.48	0.48	0.40	0.33	0.36	0.55

8.2 - RECOMMENDED TIME ALLOCATION FOR EACH SECTION

DURATION FOR EACH EXERCISE		CUMULATIVE TIME FOR THE EXPERIMENT
	CASE READING AND PRELIMINARY ANALYSIS	
30 MINUTES		30 MINUTES
	COMPUTER MODEL TUTORIAL	
15 MINUTES		45 MINUTES
	TASK PERFORMANCE WITH THE COMPUTER MODEL	
30 MINUTES		1 HOUR, 15 MINUTES
	RECOMMENDATIONS AND WRAP-UP	
15 MINUTES		1 HOUR, 30 MINUTES

8.3 - INSTRUCTION SHEET

1. Please read the given case and determine the task required to be accomplished.

2. After reading the case, please inform the investigator who will explain to you the working of the computer and the model.

   The computer model is simple to use and most of the functions can be carried out by simply clicking the mouse on the required menu. The menus are self-explanatory. They will be explained with tutorials before you start to use the model on your own.

3. In order to perform your analysis, please feel free to use the writing pad and the calculator provided to you. If questions rise regarding the use of the model during your work, please seek assistance before you proceed further.

4. Please use the given form to record any iteration data you wish for your own reference. <u>The last column, however, must contain your final recommendation</u>.

8.4 - DECISION RECORD FORM

GROUP NUMBER : ....

TIME USED : ....

Degree:
Exper.:
Video :

CONTRIBUTION AND DECISION-QUANTITIES								
Contribution								
TITLES	DECISION (NUMBER OF COPIES PER TITLE)							
Household								
World Events								
Bay Street								
Capture								
Fashion Show								
Taboos								

8.5 - LETTER OF INFORMATION

VISUAL INTERACTIVE LINEAR PROGRAMMING : THE CONCEPT, AN EXAMPLE AND AN EMPIRICAL ASSESSMENT OF ITS VALUE IN SUPPORTING MANAGERIAL DECISION MAKING.

Dear Participant:

The primary purpose of this research is to investigate the relative effectiveness of two decision support systems in dealing with the same problem.

The study entails you to spend about one-and-a-half hours to solve a case with the help of a given decision support system (DSS). Before you begin to use the DSS, you will be provided with adequate tutorials explaining the system. While you are working, the investigator will be available to answer any question regarding the case or the use of the computer system. You may finish the exercise at any time you think appropriate. The location of the experiment will be the Western Business School.

To cover the cost of your time and effort to participate in this experiment, you will receive $15. Should you withdraw from the study before the time assigned, the amount will be pro-rated. Also, if you are the top performer in your experimental group, a bonus of $100 will be awarded to you. The summary results of the experiment will be ready by December 1992; you will receive a copy as well.

The data collected in the experiment will be kept in strict confidence. You are under no obligation to participate, and if you agree to participate, you may withdraw from the study at any time without jeopardy to your academic standing. Should you have any questions regarding this research, my office is in Room 142, Western Business School. You can also reach me over phone at 671-2893.

Yours sincerely,

Arshad Taseen
Doctoral Candidate

8.6 - CONSENT FORM

VISUAL INTERACTIVE LINEAR PROGRAMMING : THE CONCEPT, AN EXAMPLE AND AN EMPIRICAL ASSESSMENT OF ITS VALUE IN SUPPORTING MANAGERIAL DECISION MAKING.

This is to confirm that I have read the letter of information, have had all questions answered satisfactorily by the Project investigator, and agree to be involved in the research project described.

....
Participant's Name

....
Participant's Signature.

....
Date.

8.7 - COMPARISON OF ACTUAL AND APPROXIMATE MAGAZINE RETURNS.

The following values of the expected returns from a demand distribution were calculated numerically on 386 PC.

$$E[R] = E[(p-x)] = \int_{-\infty}^{p} (p-x)\, f_x \, dx$$

Where R = Number of returns
p = Number of copies of a given title selected for printing.

Since the demand is assumed to be normally distributed,

$$f_x = 0.3989\ EXP[-x^2/2], \text{ therefore}$$

$$E[R] = E[(p-x)] = \int_{-\infty}^{p} (p-x)\ 0.3989\ EXP[-x^2/2]\ dx$$

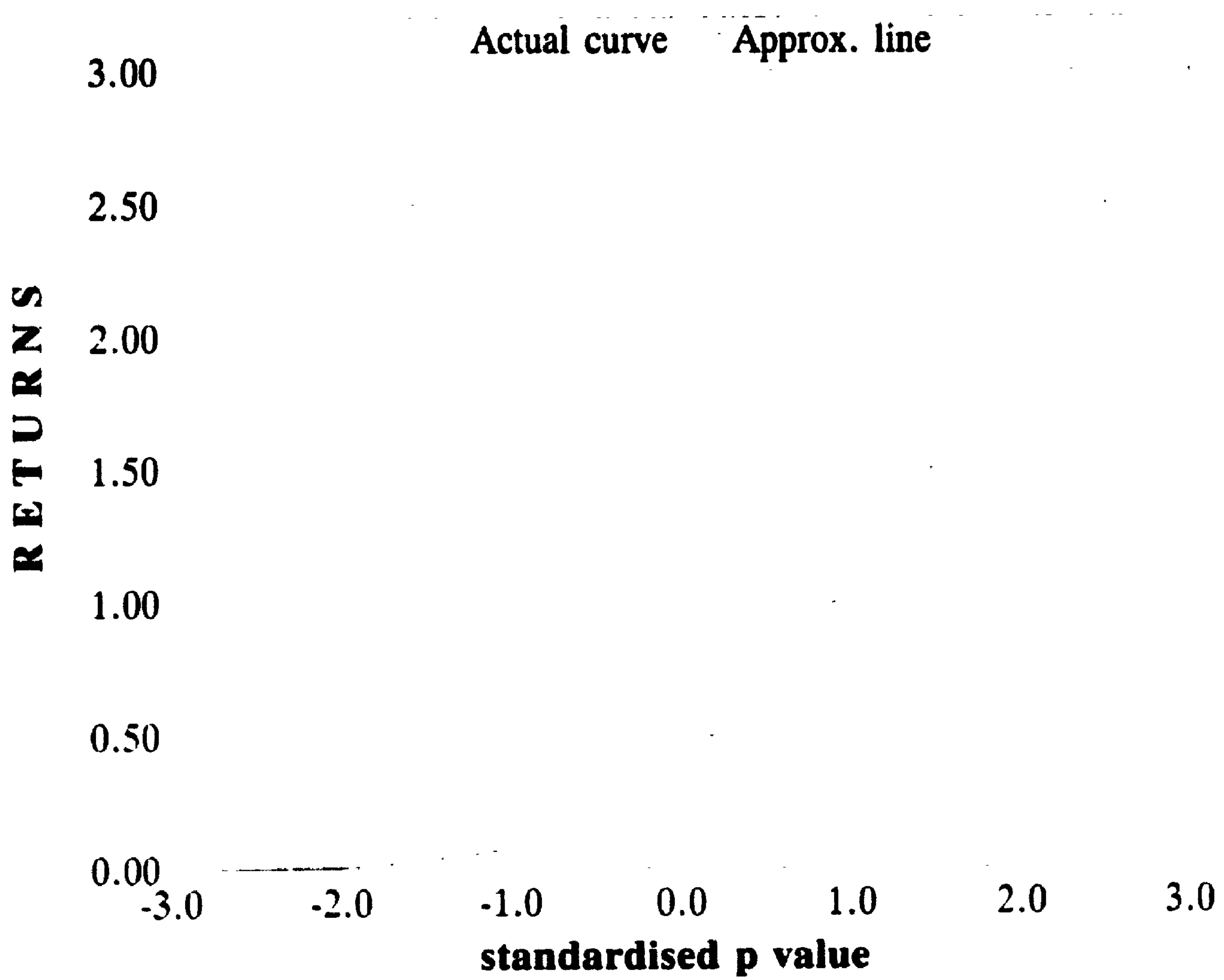
The expected returns E [R], for p in the range of -3.0 to +3.0 were calculated using the above integral and also the approximations E [R'] by the following equations:

p		E [R']
$-3.0 \le p \le -2.0$	$\Rightarrow$	[0.0218 + 0.0075 P]
$-2.0 < p \le -1.0$	$\Rightarrow$	[0.1446 + 0.0724 P]
$-1.0 < p \le -0.1$	$\Rightarrow$	[0.3727 + 0.3145 P]
$-0.1 < p \le 0.5$	$\Rightarrow$	[0.3924 + 0.5979 P]
$0.5 < p \le 1.1$	$\Rightarrow$	[0.2837 + 0.8002 P]
$1.1 < p \le 2.0$	$\Rightarrow$	[0.1201 + 0.9417 P]
$2.0 < p$	$\Rightarrow$	[0.0187 + 0.9936 P]

COMPARISON OF ACTUAL VS APPROXIMATE VALUES

P	Actual E[R]	Approx. E[R']	Error	P	Actual E[R]	Approx. E[R']	Error
-3.0	0.0004	-0.0007	0.0011	0.1	0.4509	0.4522	-0.0013
-2.9	0.0005	0.0001	0.0004	0.2	0.5069	0.5120	-0.0051
-2.8	0.0008	0.0008	-0.0000	0.3	0.5668	0.5718	-0.0050
-2.7	0.0011	0.0015	-0.0004	0.4	0.6304	0.6316	-0.0012
-2.6	0.0015	0.0023	-0.0008	0.5	0.6978	0.6914	0.0064
-2.5	0.0020	0.0031	-0.0011	0.6	0.7687	0.7638	0.0049
-2.4	0.0027	0.0038	-0.0011	0.7	0.8429	0.8438	-0.0009
-2.3	0.0037	0.0046	-0.0009	0.8	0.9202	0.9239	-0.0037
-2.2	0.0049	0.0053	-0.0004	0.9	1.0004	1.0039	-0.0035
-2.1	0.0065	0.0061	0.0004	1.0	1.0833	1.0839	-0.0006
-2.0	0.0085	0.0068	0.0017	1.1	1.1686	1.1639	0.0047
-1.9	0.0111	0.0070	0.0041	1.2	1.2561	1.2501	0.0060
-1.8	0.0143	0.0143	0.0000	1.3	1.3455	1.3443	0.0012
-1.7	0.0183	0.0215	-0.0032	1.4	1.4367	1.4385	-0.0018
-1.6	0.0232	0.0288	-0.0056	1.5	1.5293	1.5327	-0.0033
-1.5	0.0293	0.0360	-0.0067	1.6	1.6232	1.6268	-0.0036
-1.4	0.0367	0.0432	-0.0065	1.7	1.7183	1.7210	-0.0027
-1.3	0.0455	0.0505	-0.0050	1.8	1.8143	1.8152	-0.0009
-1.2	0.0561	0.0577	-0.0016	1.9	1.9111	1.9093	0.0018
-1.1	0.0686	0.0650	0.0036	2.0	2.0085	2.0035	0.0050
-1.0	0.0833	0.0722	0.0111	2.1	2.1065	2.1053	0.0012
-0.9	0.1004	0.0896	0.0108	2.2	2.2049	2.2046	0.0003
-0.8	0.1202	0.1211	-0.0009	2.3	2.3037	2.3040	-0.0003
-0.7	0.1429	0.1526	-0.0096	2.4	2.4027	2.4033	-0.0006
-0.6	0.1687	0.1840	-0.0153	2.5	2.5020	2.5027	-0.0007
-0.5	0.1978	0.2154	-0.0176	2.6	2.6015	2.6021	-0.0006
-0.4	0.2304	0.2469	-0.0165	2.7	2.7011	2.7014	-0.0003
-0.3	0.2668	0.2784	-0.0116	2.8	2.8008	2.8008	0.0000
-0.2	0.3103	0.3098	0.0005	2.9	2.9005	2.9001	0.0004
-0.1	0.3509	0.3413	0.0096	3.0	3.0004	2.9995	0.0009
0.0	0.3989	0.3924	0.0065				

PLOT OF ACTUAL & APPROXIMATE RETURNS



8.8 - ILP FORMULATION

DECISION VARIABLES:

Q_{ijk} = Quantity of *ith* magazine that will be printed during shift j, on press k. [$i \in (1\text{-}6); j \in (1\text{-}2); k \in (1\text{-}2)$]

A_{ik} = Assignment of *ith* magazine to press k. [$i \in (1\text{-}6); k \in (1\text{-}2)$]

T_{jl} = Total time (duration) machine l operated during shift j. [$l \in (1\text{-}3); j \in (1\text{-}2)$]

P_{ik} = Press time required for *ith* magazine on press k. [$i \in (1\text{-}6); k \in (1\text{-}2)$]

SUBSCRIPTS:

$i \in (1\text{-}6)$;	=	1 = Household	2 = World Events	
		3 = Bay Street	4 = Fashion Show	
		5 = Capture	6 = Taboo	
$j \in (1\text{-}2)$;	=	1 = Normal time	2 = Overtime	
$k \in (1\text{-}2)$;	=	1 = Press-1	2 = Press-2	
$l \in (1\text{-}3)$;	=	1 = Press-1,	2 = Press-2,	3 = Collator

PARAMETERS:

a_i = Contribution (in \$) per thousand i magazines.

b_l = Cost of running machine l during reserved duration.

c_l = Cost of running machine l per minute during overtime

d_i = demand of magazine i (actual quantity to be printed)

e_{ik} = time in minutes required to print thousand i magazines on press k.

f_k = time in minutes required to collate thousa... magazines that were printed on press k

FORMULATION:

Max

$$\left(\sum_{ijk} a_i \; Q_{ijk}\right) - \sum_{l} \left(b_l \; + \; c_l \; T_{2l}\right)$$

ST:

$$\sum_{j} Q_{ijk} \; + \; d_i \quad A_{ik} \qquad \leq \; d_i \qquad \text{........ For all } i \text{ and } k$$

$$\sum_{k} A_{ik} \qquad = 1 \qquad \text{........ For all } i$$

$$\sum_{i} e_{ik} \; Q_{ijk} \; - \; T_{jk} \qquad = 0 \qquad \text{........ For all } j \text{ and } k$$

$$\sum_{ijk} f_k \, Q_{ijk} \; - \; \sum T_{j3} \; = 0$$

$$T_{jl} \quad \leq g_{jl}$$

A_{ik} is binary for all i and k

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